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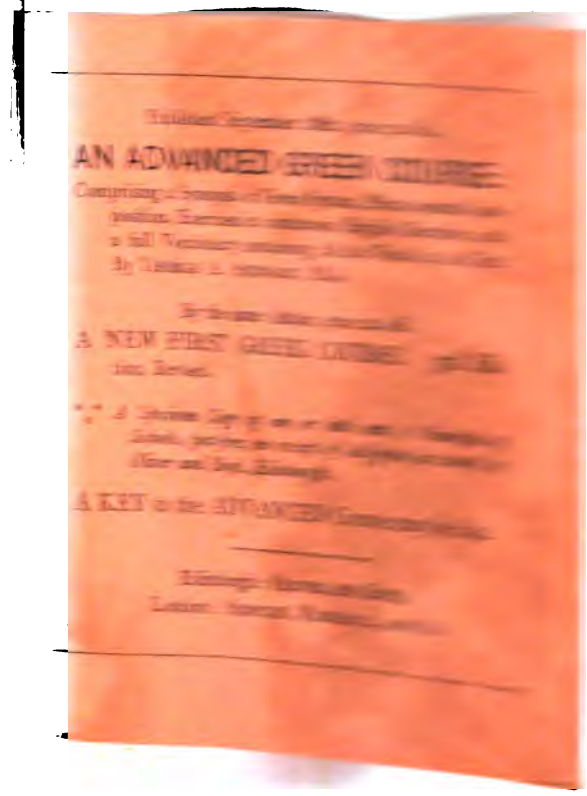

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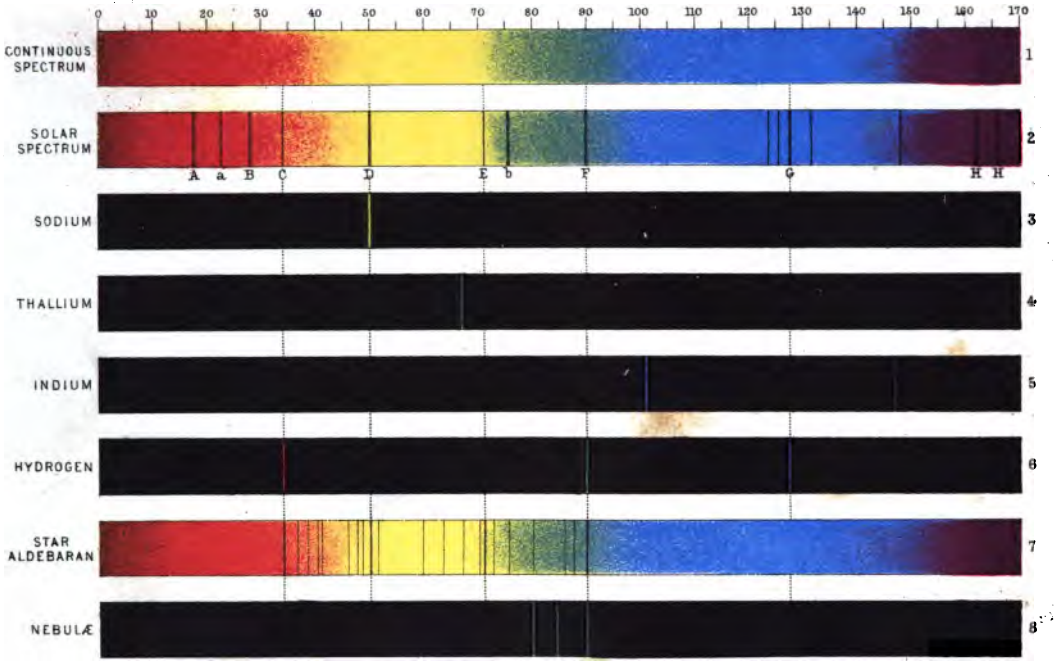

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PREFACE.

THIS little Manual is intended as a Text-Book of Physiography as prescribed by the syllabus of the Science Department, South Kensington. In Part I., which corresponds with the Elementary Stage of the subject, the Earth is considered apart from other portions of the universe, and chiefly in relation to the materials of which it is composed, the forces which act upon those materials, and the distribution of vegetable and animal life. In Part II. the Earth is considered as a planet, and its position in the solar system, as well as its relation to the distant stars, are pointed out. The chief authors consulted in compiling the work are referred to in the text.

W. LAWSON.

ST MARK'S COLLEGE, CHELSEA,
September 1880.

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PART I.

CHAPTER I.

Forces of Nature.

The endless variety of form and colour which we see in the natural world is due to the ceaseless action of various forces upon dead and shapeless matter. Strictly speaking, there is no such thing as rest in nature. The currents of air and water, the ebb and flow of the tides, the growth of plants, are obvious to all; but even in such apparently inert masses as stones and metals there is a constant vibration of particles, though it cannot be detected by the most powerful microscope. Perhaps the most universal, and certainly one of the most important, of natural forces is that of gravitation, in virtue of which a body, when unsupported, falls to the ground, and which also keeps all the planets in their orbits.

Gravitation.—Long before the time of Newton it had been observed that the earth exercised a certain kind of attraction upon the objects on its surface; but he was the first to explain the law by which this force acts, and to prove that it is precisely the same force which causes the moon to revolve round the earth, and the planets round the sun. The law of gravitation, as explained by Newton, may be thus stated:—The force with which two bodies

attract each other is directly proportional to their masses, and inversely proportional to the square of the distances between their centres. The attraction is in every case mutual. Thus the earth attracts the moon and keeps it revolving in its orbit, while the moon also attracts the earth and forms the tides. Every object upon the earth's surface is drawn towards its centre, and the weight of a body, which we feel in lifting it, is the measure of this attraction. Some bodies are heavier than others of the same volume, because they contain a greater mass, or, in other words, a greater quantity of matter. As each separate particle exerts the force of gravity, substances in which the particles are allowed to move freely naturally assume a globular form. We see this exemplified, on a small scale, in the dewdrops which hang on the blades of grass; and it is owing to the same law that the planets and other heavenly bodies are all more or less spherical.

The **attraction** of **cohesion** is probably only another form of that of gravitation, but the term is confined to that force which keeps together the atoms and molecules of a body. In solids this attraction is strong, in fluids it is weak, while in vapours and gases it is entirely wanting. It may be necessary here to mention the difference between a molecule and an atom. By a *molecule* we mean the smallest conceivable particle of a compound substance; by an *atom* the smallest conceivable particle of a simple substance. Thus a molecule must in every case consist of two or more atoms. The smallest grain of salt that we can conceive of is a molecule; but since salt is a compound of chlorine and sodium, a molecule of salt contains an atom of chlorine and an atom of sodium. A molecule of water consists of an atom of oxygen and two atoms of hydrogen. A molecule of chalk consists of five atoms, one of carbon, one of calcium, and three of oxygen. The force which keeps the molecules of a compound body together, or the atoms of the same element, is the attraction of cohesion; the force which causes the atoms of different elements to cling together and form a compound substance is called chemical attraction, or chemical affinity.

Chemical Affinity.—This force, it will be seen, is something different from the attraction of cohesion. Particles of sand and lime are found mixed together in certain rocks, but here they are held together mechanically; each substance still retains its own characteristics. When a chemical combination takes place, the compound loses the characteristics of its constituents, and forms an entirely new substance. Thus, for example, water has no resemblance either to oxygen or hydrogen. Another respect in which chemical affinity differs from attraction of cohesion is that the force varies with different substances. Some atoms combine much more readily than others. Oxygen has a strong affinity for almost every substance, and hence enters largely into compound bodies. Newton pointed out this elective affinity between certain substances. Thus, he said, if you put copper into nitric acid, the copper will dissolve and disappear; but if you plunge a piece of iron into the liquid, the copper will reappear and fall to the bottom of the glass, because the iron attracts the nitric acid more strongly than the copper does. A knowledge of the affinities which different substances have for each other is very useful to the chemist, as it helps him in many cases to analyze compound bodies.

Heat.—Another force which plays an important part in the economy of nature is heat. Heat acts in opposition to the attraction of cohesion; it turns solids into fluids, and fluids into vapours. Thus iron may be melted by the application of heat, and water is changed into steam. The three forms under which matter presents itself to us, —solid, liquid, and gaseous—depend, therefore, upon the amount of heat which they contain. Probably there is no solid which could not be vaporized if sufficient heat were applied; and certainly there is no gas which cannot be liquefied by a reduction of temperature combined with pressure. For a long time oxygen, hydrogen, and nitrogen were looked upon as permanent gases, but towards the close of 1877 M. Pictet succeeded in liquefying oxygen and nitrogen; and in Jan. 1878, with a pressure 650 times that of our atmosphere, and with a cold of 170° C., he

obtained a jet of liquid hydrogen, which became partly solid and struck on the floor with "the shrill noise of metallic hail." Scientific men believed at one time that heat was a fluid, to which they gave the name of *caloric*, but we now know that it is merely a mode of motion. That heat produces motion is a fact familiar to every one. The expansion of gases, the converting of water into steam, and the effect of steam as a motive power, are well known. Motion, on the other hand, may always be converted into heat; when motion is interrupted, heat is evolved. The natives of the South Pacific produce a fire by rubbing together two pieces of dry wood. An aerolite is ignited by the friction of the atmosphere. In both cases friction interrupts rapid motion, and heat is the result. A rifle bullet stopped by the target is melted by the heat produced. Water falling in a cataract, or waves beating against the shore, produce heat. Were the earth arrested in its orbit, the force of gravity would draw it to the sun, and immense heat would be developed by the collision. It has been calculated that the amount would equal that produced by the combustion of more than 5000 worlds of solid coal, all this heat being generated at the moment of collision. This conversion of motion into heat is explained by saying that the motion of the mass is converted into a motion of the particles of which the mass is composed. In a similar manner Professor Tyndall explains the heat produced by chemical action:—"There is, first of all, the attraction between the atoms; there is, secondly, space between them. Across this space the attraction urges them. They collide, they recoil, they oscillate. There is here a change in the form of the motion, but there is no real loss."* This vibration of the atoms continues until their motion is communicated to the surrounding ether, or, in other words, until their heat becomes radiant heat.

Ether, or, as it is generally termed, luminiferous ether, is the name applied to a subtle medium which is supposed to fill all space and to pervade all material objects. Of its precise nature very little is known. It is far more attenuated

* *Fragments of Science.*

than any gas, yet it has some of the properties of a solid, and is thought to resemble jelly rather than air. When the particles of a body are set in motion, the vibration is communicated to this invisible ether, and transmitted on all sides in a series of waves. The motion is thus transferred from the particles of the heated body to the ether, and the substance gradually cools. Were there no ether, a heated body, so far as we know, might retain its temperature for any length of time. As it is, the sun itself must cool down eventually, unless its fires are in some way replenished. Heat and light are of the same nature; they differ only in degree. There is no body in nature absolutely cold, so that in every substance there must be a vibration of the particles, though the waves thus produced in the surrounding ether may be too weak to affect our senses. A cool poker thrust into the fire becomes heated before the iron changes colour. After a time the poker is of a dull red colour; next it changes to a bright yellow, and, if allowed to remain in the fire long enough, will at length reach what is called a white heat. The increased temperature does not increase the rapidity of the original vibrations, but intensifies them, until at length we feel them. But the increased temperature also gives rise to other vibrations which are more rapid; and so long as the poker remains in the fire new and more rapid vibrations continue to be generated, while the old vibrations increase in amplitude. Hence the iron becomes more and more heated, and at length begins to glow. The vibrations which produce the red colour are of the same nature as those which produce heat, only more rapid, and the waves which they produce in the luminiferous ether are therefore shorter. Still more rapid vibrations produce the dazzling white colour which accompanies the fiercest heat of the solid iron.

It is well known that different substances have what is termed different thermal capacities. Thus, if iron, mercury, and water are exposed to the same high temperature, it will be found that the iron is hotter than the mercury, and the water cooler. Professor Tyndall tells us that in each case the amount of heat received is exactly the same,

but that this heat has two operations—one the production of tremors or vibration of particles, which raises the temperature of the body, and the other the weakening of molecular attraction; and as this internal molecular work is different in different bodies, so the amount of heat which can be devoted to raising the temperature of the bodies also varies. The great capacity which water has for absorbing heat tends to prevent any sudden changes of temperature, and hence the equable climate of places near the great ocean. Still more important is the function it performs in checking the radiation of the earth. During the day the earth is warmed by the sun's rays; after sunset the earth begins to cool. Dry air is very transparent to radiant heat, but the rays are checked and absorbed by the aqueous vapour; and as water in all its forms is itself a good radiant, the aqueous vapour not only checks the heat from passing beyond into space, but throws it back to the earth, and thus keeps it warm. The amount of aqueous vapour in the atmosphere is very small—not more, probably, than one part out of one hundred; and yet we are told that, were it not for its influence in checking radiation, the intensest cold would result in a single night, and the earth be rendered uninhabitable.

It may be urged that, if aqueous vapour is so powerful in checking radiation, it will also deprive us of much of the sun's heat. But this is only partially true. Some portion of the solar heat is no doubt absorbed, but only a small portion. The sun's rays are different in quality from those which the earth radiates, and it does not follow that a substance which absorbs the one must necessarily absorb the other. It has been proved by experiment that while the sun's rays have been transmitted with comparative freedom through a layer of water one-tenth of an inch in thickness, no single ray from the warmed earth could pass through it.

In solid bodies heat is transmitted from one part to another by conduction. All the metals are good conductors —silver the best, bismuth the worst. Wood is a bad conductor; hence workmen who use heated tools generally

have the metal instruments fixed in wooden handles. Liquids and gases are bad conductors, and the transmission of heat from one part to another is chiefly effected by convection, that is, by the intermixture of the hotter and colder portions. Thus when a kettle is placed on the fire, the particles of water at the bottom are first heated. The heat expands them, and they become lighter. Hence they rise up, while the colder water from the top descends, to be heated in turn. This process goes on until the whole mass is raised to the boiling point.

Electricity.—More powerful in some respects than heat as an agent in chemical combination and analysis is electricity. Of its exact nature very little is known. Some regard it as a fluid, of which there are two opposite kinds, vitreous and resinous, or, as they are more frequently termed, positive and negative. Others think that, like heat, it is a form of motion, and suggest that while heat is caused by a simple vibration of the particles of a body, electricity may be the result of certain compound oscillations. So early as six centuries before Christ, it was known that amber, when rubbed with silk, would attract towards it bits of straw and other light bodies, and it is from the Greek word for amber (*electron*) that our term electricity is derived. Dr Gilbert, in the sixteenth century, noticed that other substances, such as crystal, sealing-wax, and sulphur, had this same power of attraction when rubbed, and he also found that the attraction was stronger when the air was dry and cold than when it was warm and moist. Du Faye, a Frenchman, who lived in the last century, pointed out that there were two kinds of electricity, one produced by rubbing a piece of sealing-wax with cloth, and the other by rubbing a glass rod with silk; hence the terms resinous and vitreous. Finally, Dr Franklin, in his famous experiment with the kite, proved the identity of electricity and lightning.

Electricity pervades the earth, the air, and all substances, without giving any visible sign of its existence when in a quiescent state; but it is excited by heat, friction, and chemical change. Those who believe in the fluid hypo-

thesis suppose that every substance contains an indefinite quantity of the two electricities—positive and negative—mixed together, and neutralizing each other, but that these fluids may be separated. Thus, when we rub a stick of sealing-wax with a piece of cloth, the sealing-wax becomes negatively electrified, while the cloth is charged with positive electricity. Bodies charged with different kinds of electricity attract each other, but those charged with the same kind repel each other. When, owing to the various operations of nature which are constantly taking place upon the surface of the earth, the atmosphere becomes charged with positive electricity, a thunder-storm takes place. The electric fluid in passing from the clouds to the earth becomes visible as lightning; sometimes also lightning bursts out from the ground. The brilliancy of lightning is caused by the ignition of particles of nitrogen and other constituents of the atmosphere. It often assumes a zig-zag form, owing to the unequal conducting power of the air through which it passes. Sheet lightning is but the reflection of forked lightning. The passage of the lightning through the air causes it to vibrate and produce thunder. The loudness of thunder is probably due to the sudden expansion by the heat of the electric flash.

When a current of electricity passes through a body freely its presence is not felt; but if its path be obstructed, an amount of heat is evolved in proportion to the amount of resistance met with. The atmosphere is a bad conductor, and hence during a thunder-storm the electric fluid becomes visible in the form of lightning. Water is a good conductor, and during a storm the thunder-shower carries off a large quantity of electricity from the clouds to the earth. It is well known that the violence of a thunder-storm abates after a heavy fall of rain. All metals are good conductors. Glass, resin, silk, wool, india-rubber, and gutta-percha oppose resistance to the passage of the electric current, and hence are termed non-conductors. A body is said to be insulated when it is not in contact with any other bodies except non-conductors. Telegraph wires generally rest upon glass or porcelain sockets, to prevent the electric

current running down the wooden posts into the ground, and thus interrupting communication between one station and another. Though the atmosphere is a bad conductor, yet sometimes, when it is highly rarefied by heat, its coercive power is diminished, so that electricity breaks from clouds in bright sheets, without rain or thunder. This may very frequently be seen on warm summer evenings.

When a body is charged with electricity, the charge resides on the surface, and is most abundant at those parts which are most convex, or which project farthest from the general outline. Conductors, therefore, which are intended to hold their charges without leakage should have smooth surfaces. On the other hand, if the conductor is intended to give off or receive electricity readily through the air, it should be furnished with pointed projections. It is for this reason that the upper extremities of lightning-conductors are pointed. It was Dr Franklin who first suggested that all large buildings should be supplied with stout pointed metallic rods, extending into the air to some distance above the highest point of the building, and carried down into the ground. By this means the destructive effects of the lightning may generally be avoided. If, however, the conducting rod is allowed to get out of repair, or is too thin, it is worse than useless, for it attracts the lightning without being able to carry it off, and thus buildings are sometimes destroyed.

Without actual contact, positive electricity tends to produce negative electricity in bodies near it, and *vice versa;* the latter are said to be electric by induction. When thunder-clouds are very low the electricity produced by induction is sometimes so great that it escapes from pointed objects in the shape of flames. These flames, known as "St Elmo's fire," are not unfrequently seen at the topmasts of ships and at the extremity of their yards. The phenomenon is explained on the supposition that the uncharged body contains a store of both kinds of electricity, exactly equal in amount, and therefore quiescent. When a body charged with positive electricity is brought into proximity to it, all the negative electricity is attracted

to the near side, and the positive electricity repelled to the far side.

Towards the close of the last century a celebrated controversy sprang up between two Italian professors, Galvani and Volta. The former noticed that the hind legs of several frogs, which his wife had prepared for soup and hung up by copper hooks upon an iron balcony outside his house, were convulsed as if in contact with an electric machine. He supposed, therefore, that there was electricity in the leg of the frog. This discovery was much talked about at the time, and this form of electricity was termed galvanism. Volta disputed the theory, and explained the convulsions by saying that the electric current was caused by the metals, iron and copper, being brought into contact through the medium of the moist flesh. To prove his point he constructed a pile of alternate discs of zinc and copper, with small pieces of moistened flannel between. The battery ends with a plate of zinc at the bottom and of copper at the top, and these are connected with a wire. A chemical action takes place between the metals, and the result is a current of electricity which runs through the wire from one end to the other. He explained that in the same way, when the leg of the frog was blown by the wind against the iron balcony, the two metals, iron and copper, were connected, and a current of electricity produced. This was, no doubt, the right explanation, though Galvani was also right in contending that there is electricity in animal tissues.

The *voltaic pile*, as it is termed, is interesting to us as containing the germs of the electric telegraph and the electric light. It showed that an electric current could be sent for any distance along a wire the two ends of which are joined to the poles of a battery; and within forty years the telegraph had been invented. Again, if the connecting wire of the pile be cut in two, and the ends tipped with charcoal, a bright spark will glow between the points so long as the battery is at work; for charcoal is a bad conductor, and the electric current being interrupted, heat and light are evolved. Sir H. Davy, in 1808, with

a battery of 2000 pairs of plates, succeeded in producing a bright luminous arc, four inches long, between the carbon terminals. It is on this principle that the electric light is constructed.

Magnetism seems to be of the same nature as electricity, though it differs from it in some particulars. There are two opposite kinds of magnetism, just as there are two kinds of electricity. Every magnet contains both kinds in equal quantity—usually confined one to each half of its length. And as with electricity, so with magnetism, the opposites attract, like kinds repel. If a piece of soft iron be held close to a magnet it will be attracted to it. The extremity of the magnet induces in the near end of the iron a kind of magnetism opposite to its own, and in the opposite end a kind similar to its own. In fact, for the time, the iron itself becomes a magnet. The process is similar to electrical induction. The magnet is found as an iron ore in a natural state, but its properties may be communicated to other substances; and steel, when magnetized, retains these properties with little change.

If you take a straight bar magnet and apply each end in succession to a needle, it will be found that both ends attract the needle equally. If now you take the needle and draw it from eye to point along one end of the magnet, you will find that while one end of the magnet attracts one end of the needle the other pole of the magnet repels it. The needle itself has become a magnet, with its two kinds of magnetism. If the magnetized needle be suspended close to one end of the magnet, the point of the needle will be attracted, the eye repelled; if the needle be removed to the opposite end, the eye will be attracted, the point repelled. If, however, the needle be suspended near the middle of the magnet, neither end of it will be attracted or repelled. This seems to prove that the magnetic force is neutralized in the middle point; but this is not the case, for if the magnet be broken into two equal parts we find we have two perfect magnets. One theory is this: Magnetism is supposed to consist of two invisible fluids, self-repellant, but mutually attractive. When a

piece of steel becomes magnetized, the opposite fluids are arranged on opposite sides of each molecule, so that all those containing positive magnetism point in one direction, and those containing negative attraction point the opposite way. The act of magnetization consists merely in the separation of the two fluids which existed in the steel before, but were neutralized by their coalescence.*

The ancients seem to have been acquainted both with natural and artificial magnets; but the important fact that the magnet-needle, when suspended on a pivot, always disposes itself in a north and south direction was not discovered until the fourteenth century. The Chinese, indeed, are said to have been acquainted with this property of the magnet as early as the seventh century B.C.; but if they were, they made no practical use of their knowledge, and the honour of having invented the *Mariner's Compass* fairly belongs to Flavio Gioja, who was born at Amalfi, near Naples, about the commencement of the fourteenth century.

The connexion between electricity and magnetism was proved by a series of experiments carried on in France and England early in the present century. Ampère showed how it was possible to magnetize a steel bar by passing an electric current round it: Faraday reversed the experiment, and showed how a magnet could be made to produce an electric current. Now, it is known that certain electric currents pass round the earth from east to west, and it has been suggested that these may turn the earth into a great magnet, and thus explain the motions of the magnetic needle. This theory is strengthened by a discovery made by Professor Seebeck in 1822, who proved that heat acting upon two metals will produce a current of electricity without the aid of acid and water. It is not improbable, therefore, that the heat of the sun, acting upon the metals contained within the earth's crust as it rotates from west to east, may cause the currents of electricity which flow from east to west, and that these in turn govern the movements of the magnetic needle.

* Tyndall: *Fragments of Science.*

CHAPTER II.

The Crust of the Earth.

An opinion at one time prevailed that the interior of the earth was a molten mass, and that this internal fire was surrounded by a comparatively thin crust of solid land. Mathematicians have proved that this opinion is no longer tenable, and it would be hard to reconcile it with the great density of the globe, which is twice that of granite, and about five and a half times that of water. Even supposing the interior of the earth to be solid granite, we can hardly account for this density, and it has been conjectured that it consists for the most part of metals. Confining our attention, however, to that portion of the earth's crust which comes within the limits of human observation, we find that it is composed of a vast number of substances of various kinds and of different combinations. But just as the thousands of words which compose the English language are built up out of the letters contained in the alphabet, so the various substances found in the crust of the globe and in the organic tissues of plants and animals are composed of a comparatively few elements.

In analyzing compound bodies, and reducing them to the elements of which they are formed, various methods are used by the chemist. Sometimes the substance is burnt, and the gases and vapours which it gives off, as well as the ashes which are left, are carefully examined. Sometimes, relying upon his knowledge of elective affinities, the chemist tests the compound by means of another substance. Thus, if we dip a litmus paper into any solution containing an acid it turns red, while an alkali turns the red paper blue. Electricity, again, is a very powerful agent in decomposing fluids; by this means Sir

H. Davy resolved water into oxygen and hydrogen, and this method of analysis was afterwards thoroughly worked out by Faraday. In more recent years the method of spectrum analysis—to which we shall have again to return in a future chapter—has been remarkably successful in discovering the minutest trace of a metal in any substance, and by its means several new metals have been discovered.

Elements of Matter.—At present about sixty-six elementary substances are known to the chemist, and every year adds one or more to the list, the most recent addition being a metal which has been named Norwegium. On the other hand, Mr Norman Lockyer has raised the question whether many, if not all, the so-called elements are not in reality compounds. His arguments cannot be understood without some knowledge of spectrum analysis, and they cannot be discussed in this place. It is sufficient to say here that Mr Lockyer makes out a strong case, and that it is not at all improbable that ultimately it may be found that all the elements can be reduced to one. For the present, however, we must continue to apply the term element to those substances which hitherto have resisted any further decomposition.

Of the sixty-six elementary substances, fifty-one are metals, leaving only fifteen non-metallic substances. All the metals, except mercury, are solids; mercury and a non-metallic element called bromine are, in ordinary temperatures, liquids; while other elements, such as oxygen and hydrogen, are gases. Mercury, when exposed to the cold of the Polar regions, becomes solid, and may be hammered like lead; on the other hand, if exposed to a high temperature, it is changed into a vapour or gas. Oxygen, hydrogen, and nitrogen, though once called permanent gases, have, as we mentioned in the last chapter, been reduced to liquids, and hydrogen has even been solidified. All the metals are easily fusible, though at different temperatures, and, if the heat be continued, pass from fluids into gases. Some substances, however, such as carbon, do not seem to liquefy, but, with a high temperature, pass at once from the solid to the gaseous state.

The simple elements are very unequally distributed in nature. Thus oxygen forms one-fourth part by weight of the whole atmosphere, and nearly nine-tenths by weight of the whole of the water upon the globe. It also forms, in combination, nearly one-half of the solid crust of the earth. Silicon forms about a quarter of the earth's crust; next rank in order aluminium, iron, calcium, magnesium, sodium, potassium, and carbon. These nine together have been estimated to constitute $\frac{977}{1000}$ of the earth's crust, all the other elements together contributing less than one-fortieth. The atmosphere is mainly composed of two gases, nitrogen and oxygen; water is composed of oxygen and hydrogen. But in one case the gases are merely mixed; in the other they are chemically combined. Water has no resemblance to either oxygen or hydrogen, one of which is the most inflammatory and the other the most inflammable of gases. In the air there is a merely mechanical mixture of two gases, without any chemical change.

If we consider the nine elements which enter most largely into the composition of the earth's crust, we find that six of them are metals, and we have seen that metals form three-fourths of the total number of elementary substances at present known. This preponderance of the metals is not what we should expect from ordinary observation: on the contrary, we are accustomed to consider metals of all kinds as rather scarce. But the fact is, that metals are very seldom found in a pure state; they are generally found in combination with oxygen or some other substance, and the combination entirely alters their character. Thus oxygen combined with iron forms rust; with sodium it forms soda; with potassium, potash; and with magnesium, magnesia: thus the metallic origin of these compounds is hidden or obscured.

Chemical Compounds.—The chief chemical compounds are either binary, or those containing but two elements, as water, for example; ternary, consisting of three elements, as marble, which consists of carbon, oxygen, and calcium; or quaternary compounds, which contain four elements, as alum, which consists of sulphur, oxygen, aluminium, and potassium. The chief binary compounds are those of

oxygen with some other substance. Such compounds are termed *oxides;* thus iron rust is the oxide of iron; red lead is the oxide of lead; platina, soda, magnesia, and silica are the oxides, respectively, of platinum, sodium, magnesium, and silicon. The compounds of chlorine are termed chlorides; thus common salt is the chloride of sodium. Recent experiments, however, seem to prove that chlorine itself is a compound of oxygen and an element which it is proposed to call murium. Oxides which contain a large proportion of oxygen exhibit *acid* properties: sulphuric acid is a compound of sulphur and oxygen; carbonic acid, of oxygen and carbon. Other binary compounds besides those of oxygen are acids: thus hydrochloric acid is a compound of hydrogen and chlorine. When an oxygen acid combines with certain oxides, such as soda and magnesia, a *salt* is produced. The name of the salt is formed by changing the termination of the acid into *ate*, and placing it before the name of the oxide. Thus sulphuric acid combined with soda forms the sulphate of soda, or Glauber's salt; with magnesia it forms the sulphate of magnesia, or Epsom salts. These salts are, of course, ternary compounds. The oxides which, when united with an acid, form salts, are termed basic oxides, or, more briefly, bases.

Chemical research during the present century has thrown considerable light upon the nature and method of chemical combination. Dalton, early in the century, discovered the law of *multiple proportion*, by which is meant that each element has a fixed weight of its own, and will only combine with other elements in proportion to this fixed weight. For example, if carbon be heated, 12 parts by weight of carbon will take up 16 of oxygen to make carbonic oxide, or twice $16 = 32$ to make carbonic acid, but it will not take up anything between these weights. Again, oxygen will join itself to nitrogen in five different proportions, making five different substances, and in each case a multiple of the same fixed weight is added.

Silicon.—Next to oxygen, silicon is the most widely-diffused element in the earth's crust. It is never found

pure, but its oxide, silica or silicic acid, is a chief constituent in many rocks. Sand is generally composed of grains of quartz, and quartz is almost pure silica. Sandstone, again, is simply consolidated sand, the particles having been bound together either by pressure or the infiltration of lime, oxide of iron, or other cementing material. Granite is a compound of quartz, felspar, and mica. Felspar is chiefly composed of silica, alumina, and potash; while mica is a compound of silica, magnesia, and potash. Flint is an impure form of silica. Gneiss, an important ingredient in the older sandstones, is almost entirely composed of it. A multitude of other rocks, such as the volcanic products termed trap, basalt, and lava, as well as various clays, are silicates—that is, compounds of silicic acid with a metallic oxide.

The metals which compose such a large proportion of the simple elementary substances have been divided into four classes:—1. Metals of the alkalis; 2. Metals of the alkaline earths; 3. Metals of the earths proper; 4. Metals proper.

To the first group belong potassium and sodium. The term *alkali* was first applied by the Arabians to the carbonate of soda found in the ashes of sea-weed, and afterwards to the carbonate of potash obtained by burning land plants. These carbonates are now termed mild alkalis, in contradistinction to the caustic alkalis, soda and potash, obtained from them. The characteristic properties of an alkali are a peculiar taste, the power of changing vegetable reds into blues or greens, and yellows into browns; and the power of neutralizing acids when added in sufficient quantities. Thus soda and potash neutralize carbonic acid when combined with it, forming the compounds carbonate of soda and carbonate of potash respectively. Potash and soda, it will be remembered, are not simple elements, but oxides of the metals potassium and sodium. **Potassium** has a brilliant white colour shaded with blue, and in ordinary temperatures is soft like wax. At the freezing point, however, it is hard and crystalline. As a metal it has no particular value.' The substance is found as potash

in granite, trap, and other igneous rocks, where it is associated with silica. From the disintegration of these rocks it finds its way into soils, from whence it is extracted by plants. **Sodium**, like potassium, is never found free, and can only be obtained by difficult chemical processes. It has a reddish-white colour, and is soft and adhesive at ordinary temperatures. As a compound it is very abundant in most soils and in marine plants. The chloride of sodium is common salt.

The second group of metals comprises calcium and magnesium, and two others, barium and strontium, less widely distributed. All the metals of this class are obtained with difficulty, and are never found but in combination with oxygen or some other element. **Calcium** is described as a silver-white metal. Combined with oxygen it forms quicklime. The carbonate of lime is limestone; and the sulphate, gypsum. Chalk is a softer kind of limestone, while marble is a hard crystalline form of it. The finer varieties of gypsum form alabaster and selenite. **Magnesium** is a metal said to resemble zinc. Its oxide, magnesia, readily combines with carbonic acid, and is sometimes found in nature as a carbonate. Combined with the carbonate of lime it forms magnesian limestone.

Most if not all the limestone rocks we meet with in various parts of the world are of organic origin, and have been formed out of shell-beds, coral reefs, and the accumulations of the remains of Foraminifera. In the South Pacific, and, to a less extent, in the Atlantic and Indian Oceans, thousands of islands are now being formed by the coral zoophyte; and extensive beds of chalk are being deposited at the bottom of the Atlantic. In mid-ocean, wherever the depth does not exceed 2500 fathoms, a whitish substance is brought up from the bottom, which is almost entirely composed of minute shells. These belong, for the most part, to a genus of Foraminifera called *Globigerina*, and are scarcely distinguishable from the microscopic shells which constitute a large portion of the chalk of Europe.

Coral Islands.—The reef-building coral cannot exist where the temperature of the water is less than 70° Fahr.;

hence it is seldom met with more than 30° from the equator; and even within these limits it is restricted by the depth and quality of the water. The coral cannot exist quite close to land on account of the impurity of the water, and cannot live at a greater depth than about 25 fathoms.

Corals are propagated by divisions, buds, and eggs. The young coral leaves the egg as a minute oval body, and it swims about with great activity by the help of multitudes of little hair-like filaments called cilia, with which it is covered. After a while it settles to the bottom, loses its cilia, and, becoming fixed to the rock, gradually assumes the form of its parent polype. The white coral spreads over the bottom of the ocean like turf, and has the power of dividing and subdividing itself to any extent. Other corals throw out buds which grow into branches until a tree-like mass is formed. At the end of each branch there is the appearance of a flower. This is the mouth, which is surrounded by a hair-like fringe, by means of which the polype collects its food. The solid part of the coral is the skeleton, outside of which is a jelly-like skin, which is the soft part of the animal. When the coral dies the skin decays and drops off, while the skeleton remains. In coral districts thousands are at work on one spot, and when any die others take their places. Thus in time a large reef is built up, the interstices between the branches of coral being filled up with sand, shells, and fragments of coral broken off by the waves. The corals go on building until the reef reaches the surface of the water. Gradually a thin soil is formed by the action of the waves, a seed is dropped by some passing bird, and vegetation springs up; thus gradually the coral reef is formed into an island.

Coral formations are of four kinds—the fringing reef, the barrier reef, the encircling reef, and the atoll. The fringing reef is near the shore. Such reefs are found in the Atlantic, the Indian Ocean, and the Pacific. A barrier reef is at some distance from the shore, with a deep channel between. We have a fine example on the north-east coast of Australia. The reef extends for a distance of about 1000 miles, and the channel between it and the shore is

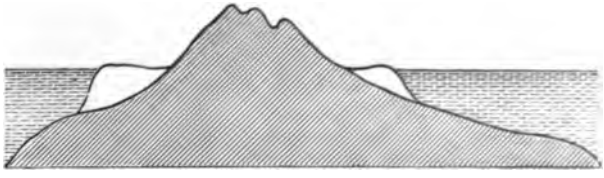
navigable throughout. The reef does not rise above the water, but its presence is marked by a tremendous surf, accompanied by an unbroken roar of deep thunder. Encircling reefs generally form a ring round some island, at a distance of two or three miles from it. We have an example in Tahiti, the largest of the Society group. Atolls are rings of coral with a lagoon in the centre. Such reefs are common in the Pacific, and there are some interesting examples in the Laccadive and Maldive islands, in the Indian Ocean.

It will be seen from the accompanying diagrams (Fig. 1) that the four kinds of formations we have mentioned are but different stages in the growth of coral islands. In the first place, the coral builds near, though not quite close, to some island, and forms a fringing reef. If the island remains stationary the reef may increase in breadth, but it will still remain a fringing reef. If, however, the land were to subside slowly, and the colony of zoophytes still keep at work, there would gradually appear a channel of clear water between the reef and the land, and we should have an example of an encircling reef. If the same process still went on, the island in the centre would at length disappear, and an atoll would be formed. It follows from this explanation that wherever we meet with atolls or encircling reefs the land must have slowly subsided; but where fringing reefs are met with, the bed of the ocean must either be stationary or rising. In the Atlantic the fringing reef is the only kind of coral formation met with; in the Indian Ocean we have examples of all four kinds; in the Pacific fringing reefs seldom occur, while atolls are numerous.

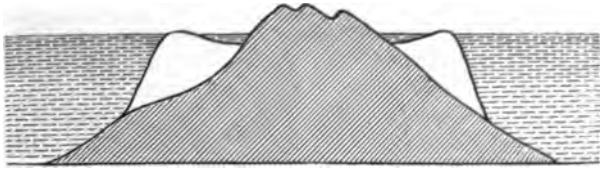
We thus see that the same causes which built up the limestone rocks which now form such an important part of the earth's crust are still at work; and that the solid matter—carbonate of lime—of which these rocks are formed has been extracted by the zoophytes from clear sea-water, in which it was held in solution.

Limestone is easily dissolved by water which contains carbonic acid; and as most water obtains some portion of

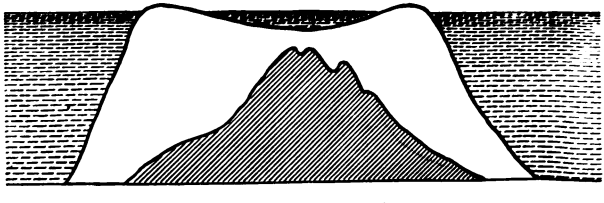
FIG. 1.—CORAL FORMATIONS.



Section of an island surrounded by a fringing reef.



Section of an island surrounded by an encircling reef.



Section of a coral island, or atoll, with central lagoon.

this acid either from the atmosphere or from the soil through which it percolates, it follows that in limestone districts the rocks are eroded by the action of water to a considerable extent. In many places, as in Derbyshire, for example, large caverns have been formed in this way, the rocks having been dissolved by running water. These caverns often contain beautiful *stalactites* hanging like icicles from the roof, or *stalagmites* rising from the floor. The water sinking through the rocks above absorbs a quantity of carbonate of lime, and when it reaches the roof of the cavern it deposits a portion of this in a solid form. Every succeeding drop leaves its tiny burthen, and in process of time the stalactite reaches a considerable length. From the point of the stalactite water drops to the floor, and here another little calcareous deposit is formed, which gradually grows upwards and forms the stalagmite. In some cases the two unite and form a slender pillar reaching from the ground to the roof. There is a fine example of this in a cavern near Castleton, in Derbyshire. A recess in the cavern, owing to the appearance presented by the stalactites and stalagmites, is called the Organ Chamber.

Among the metals of the earths proper, **aluminium** is the most important. It is never found in a native state, but can be produced at a moderate expense, and has been put to a variety of uses. Its oxide, alumina, is very abundant in nature. Combined with silica it forms clays of various kinds; and the silicate of alumina combined with potash forms felspar, one of the constituents of granite and other igneous rocks. The disintegration of some kinds of granite is owing to the action of rain water charged with carbonic acid which it has obtained from the atmosphere. The acid dissolves the potash and a portion of the silica, leaving the excess of silica and the alumina still united in the form of a clay. Slates of various kinds are formed from clay, as sandstone is from sand. Sometimes, owing probably to exposure to heat under great pressure, slates assume a semi-crystalline appearance. *Shale* is the name given to a softer kind of slate. The sulphate of alumina combined with the sulphate of potash forms alum.

In the group of metals proper are included gold, silver, platinum, iron, lead, copper, quicksilver, nickel, tin, zinc, antimony, arsenic, manganese, bismuth, and others less common. Gold, silver, platinum, and a few others are occasionally found in their natural state as metals. The great majority, however, are chiefly found as ores. Sometimes the ores are alloys or combinations of different metals: more frequently they are salts or oxides of the metal. The ores of lead, zinc, copper, and antimony are frequently sulphurets. Platinum is the heaviest metal known, and is nearly twice the weight of lead.

Iron is seldom found native, except in those masses to which a meteoric origin is usually assigned. When the term *native* is applied to a mineral, it is meant that it is either pure or alloyed with other metals which do not disguise its character. Iron in this country is usually found as an ore called ironstone, which consists of carbonate of iron mixed with clay. The iron is separated from its ore by means of a blast furnace. The so-called meteoric iron is generally alloyed with nickel, and to a less extent with other metals, such as cobalt, tin, copper, and manganese. It generally occurs in large detached masses, and some think that these masses are fragments of meteors, or shooting stars, which have reached the earth. The most remarkable of these—that of Otumpa—was discovered in the desert of the Gran Chaco, in South America. It was brought to England, and is now in the British Museum; it weighs 14 cwt. Another mass, found in Siberia, weighed 1600 lbs., and there is one in Yale College, Massachusetts, weighing 1635 lbs., which came from Texas. The great mass of Otumpa was far from being a solitary one in that region. Similar masses are common in the province of Atacama, in Peru; in South Africa, on the north-western coast of Greenland, and in other places. These facts have led many writers to doubt their meteoric origin. Professor Judd thinks they have been produced by volcanic action.

Many of the metals are found almost exclusively in veins. These are cracks or fissures in the rock which have been filled, or partially filled, with mineral substances; and it

is supposed that these substances have been brought by sublimation from the heated interior of the earth and deposited at a lower temperature. In Cornwall, where the richest tin-mines in Europe are met with, the most productive veins run almost universally from east to west. Veins at right angles to these are generally non-metalliferous, or if they do contain metallic ores, they are of a different kind. From this circumstance it has been conjectured that there is some connexion between these veins and the electric currents which circulate through the earth at right angles to the magnetic meridians. The prevalence and richness of mineral veins are also intimately connected with the proximity or junction of dissimilar rocks. Granite and other igneous rocks are often eminently metalliferous. Mineral deposits are also abundant in sedimentary rocks, especially where the two classes come in contact, or where metamorphism has taken place. In Great Britain no metal, except iron, is found in any stratum newer than the magnesian limestone. This is probably due to the fact that the more recent systems of rocks in this country have not been exposed to any great volcanic disturbance; for, in Auvergne and the Pyrenees, mineral veins occur in more recent strata.

Carbon forms the greater portion of the structure of all organic substances, and it is remarkable for the number and variety of its compounds. It exists in nature in a pure state in the diamond. Next to the diamond, the purest natural form of carbon is graphite or plumbago, commonly called black-lead, though there is no particle of lead in it. Iron is frequently present in graphite, but in its purest form it consists almost entirely of carbon. Charcoal and lamp-black are artificial forms of carbon. Combined with oxygen it forms carbonic acid; and this gas, as we have seen, readily combines with lime, magnesia, and other bases to form solid compounds. In union with hydrogen it is the chief constituent of coal, and along with oxygen, hydrogen, and nitrogen it is an abundant ingredient in plants and animals.

Coal is generally found in "basins," or large concave

depressions in the earth's crust. The coal-measures, as the coal-bearing strata are termed, consist of alternate beds of clay, coal, and sandstone; and the seams of coal vary in thickness from three to nine feet. In South Wales the coal-measures are said to attain a thickness of 12,000 feet. It is now generally admitted that coal has been formed almost entirely out of decayed vegetation. In many cases the coal-basin probably occupies the site of an ancient delta which was covered with jungle, such as we now see in the deltas of the Ganges and Mississippi. It seems also probable that while the coal-measures were being formed, the ground was gradually sinking. The mass of vegetation which covered the delta was at length submerged and covered with accumulations of sand and mud brought down by the rivers. In process of time a comparatively dry surface was formed, another covering of vegetation sprang up, to be in its turn submerged and buried. These several masses of vegetable matter, fermenting under pressure, and probably exposed to the internal heat of the earth, gradually became carbonized and changed into coal. What makes the theory more probable is, that under almost every seam of coal is found a band of clay, and in this clay are discovered the roots of trees which belonged to the ancient forest growth; while the remains of stems, leaves, fruits, and flowers are found in great abundance in the sandstones and shales which lie above the seams. In the Sydney coal-field in Cape Breton Island there is clear evidence of at least fifty-nine fossil forests ranged one above the other.

During the various changes and upheavals that have taken place in the Carboniferous strata—changes to which, as we shall see afterwards, the whole crust of the globe is exposed—the coal-measures have in some instances been exposed to a considerable temperature, and the heat has been sufficient to deprive the coal of its bitumen and change it into a kind of coke called *anthracite coal.* This variety is very useful for steam purposes, as it burns without smoke and with very little flame, but throws out great heat. Occasionally it is so hard that it has been made into inkstands and ornaments. Sir Charles Lyell is of opinion that

graphite is merely another form of anthracite. *Jet* is undoubtedly a kind of coal, though in England it is not found in the Carboniferous system, but in more recent strata.

It is not improbable that some of our coal-fields have been formed out of accumulations of vegetable matter similar to the peat-bogs of Ireland. Peat in this country is mostly formed out of the plants known as bog-mosses; and when not checked by drainage and cultivation, the peat-moss spreads wherever there is stagnant water, sometimes invading forests, which it first destroys and then buries. Hence in peat-mosses we often find the remains of oak, pines, and other trees. In some cases, where the peat is of recent formation, it consists of a loose, fibrous turf; but where it has been accumulating for hundreds, and perhaps thousands of years, it is a solid and compact mass, with many of the characteristics of coal. The jungle growths of tropical countries and the cypress swamps of the United States are analogous to peat-mosses, and are probably laying up material for future coal-fields.

CHAPTER III.

Geological Systems.

All the various materials that form the crust of the earth have been grouped by geologists into two classes,—stratified rocks and unstratified rocks; the term rock including not only the more solid masses of limestone, sandstone, or slate, but also the less compact materials, such as sand, mud, clay, and gravel. The stratified rocks are so named because they occur in regular layers or strata, as may often be seen in a quarry or railway cutting; the unstratified rocks exhibit no traces of stratification. The former, again, differ from the latter in containing fossils, or the remains of plants and animals hardened into stone. The presence of these fossils proves that the stratified rocks must at one time have been in a soft and plastic condition, and a careful study of the nature and position of these rocks, as well as of the fossils embedded in them, has led to the conclusion that all stratified rocks have been formed by the agency of water, and they have therefore been termed *aqueous* rocks; while the other group seem to have been formed by the action of fire, and are therefore termed *igneous* rocks.

The aqueous rocks owe their origin to forces which are still at work. The mud which formed the various shales, slates, and flagstones has been carried down by rivers and deposited in lakes and seas. The sandstones which are so numerous have been formed out of long stretches of sand, such as we now see lining our shores. The limestones and beds of chalk have been built up in the deep ocean by myriads of coral and beds of minute Foraminifera. The thick seams of coal speak of extensive peat-mosses, or of dense jungle at the mouths of rivers. It follows from this, then, that the strata must be of different ages, and

that, as a rule, the lower strata must be more ancient than those above them. The various rocks can therefore be classified according to age, and geologists have been able to accomplish this with the utmost certainty by carefully studying the fossils. It has been ascertained that each system of rocks has its own characteristic fossils. Shells are very abundant in some strata, various kinds of vegetation in others; gigantic lizards characterize another group of rocks, while the more recent systems contain the remains of animals and plants allied to those which are now in existence.

An interesting point connected with the fossils found in the various systems is, that there seems to have been a gradual progress from lower to higher forms of life during geologic ages. In the oldest rocks of Great Britain—taking those as the oldest which occupy the lowest position—we find the remains of shell-fish and traces of sea-weeds; in those immediately above them, remains of fishes with backbones; next we find traces of land animals, and then birds. Still higher in the scale we meet with the fossils of marsupial animals allied to the opossum and kangaroo, while in the more recent formations we find species belonging to every existing order of animals except man. The same law holds with respect to fossil vegetation. The sea-weeds and mosses of the earlier systems are succeeded by a semi-tropical vegetation in the Carboniferous rocks; and this, in turn, gives place to the trees and plants of temperate regions. It thus appears that, during the countless ages that preceded the appearance of man upon the globe, the earth must have undergone great and numberless changes in climate and external conditions. But all these changes seem to have resulted in adapting the earth for higher and higher forms of life, until at length it became a suitable abode for man.

It will have been observed that most of the forces which helped to form the aqueous rocks—the action of the sea, the influence of weather, the effect produced by running water—are *degrading* forces: they tend to wear down and level the surface of the globe. In opposition to these

there has always existed a contrary upheaving force, and its results are still observable in the phenomena attending earthquakes, volcanoes, and boiling springs. At present the intensity of volcanic action is confined to certain well-known tracts in different parts of the globe; but there is no part of the world where traces of earthquakes and volcanoes cannot be found. The basaltic pillars of Giant's Causeway and Fingal's Cave, the whinstone dykes so well known to miners in the north of England, are but the ancient lavas of volcanoes which once existed in full activity in the British Islands. And even where the more violent manifestations of igneous activity are now absent, the effects of the upheaving force may be seen. There is scarcely any spot upon the globe where land is perfectly stationary: in some places it is gradually rising, in others slowly sinking. There is evidence to show that the whole east coast of Scotland has been raised twenty feet since the time when the Romans occupied this island.

We have thus two well-defined classes of rocks differing in origin and character—the one formed by the agency of fire, the other by the agency of water. Besides the two main divisions, there are two sub-classes which it may be convenient to remember: they have been termed respectively Metamorphic and Plutonic rocks.

A careful examination of the aqueous rocks shows that many of the most ancient formations, and also some of the more recent, have undergone a certain change or metamorphism, owing chiefly to exposure to heat. The effect has been to harden and crystallize the strata, to obliterate all traces of fossils, and, in some instances, to destroy all marks of stratification. Hence a few years ago the metamorphic rocks were considered a separate system, and supposed to embrace the oldest of all strata. More recent investigation has proved, however, that metamorphism is confined to no particular period in the past. It is most common among the ancient systems, because they have been longer exposed to the changes that have taken place in the earth's crust. But metamorphic rocks are found in the Alps belonging to the Tertiary period. The term,

therefore, is now applied to stratified rocks of any system that have undergone change owing to exposure to great heat.

In aqueous rocks, therefore, we have two distinct classes: those in their natural state, and those that have undergone metamorphism. The igneous rocks may also be divided into two classes: volcanic and *plutonic*. Of the former we have already spoken, as being the remains of ancient lavas and other volcanic products. The plutonic rocks include all granites and certain porphyries. They seem to have been formed by the melting and cooling of rocks at great depths, under the pressure either of water or of other masses of rock; and they differ from volcanic rocks in their more perfect crystallization, and seem rarely, if ever, to have overflowed the neighbouring strata, as is often the case with basalt.

We shall now give a brief sketch of the various systems of sedimentary rocks, beginning with the most ancient. Of course, as the science becomes better known, geologists enter more and more into detail, and new systems are added to the old classification. The systems given below are those generally recognised at the present day, and the student will have no difficulty in assigning its proper place to any new system that he may come across in the course of his reading.

Laurentian System.—This is the oldest system of stratified rocks, so far as is known at present. The strata are hard and crystalline, showing a great amount of metamorphism, and consist of gneiss and quartz, with interstratified limestone of great thickness. These rocks are largely developed in Canada, to the north of the river St Lawrence; and they are also met with in Bohemia, in the Hebrides, and on the north-west coast of Scotland. The only fossil that has yet been detected is a very minute shell, which has been named the *Eozoon Canadense*. The limestone in which it was first detected was 1000 feet in thickness, and is supposed to have been entirely formed by those minute Foraminifera, which appear to have grown one layer above another, and to

have formed reefs, just as the coral polype is doing at the present day.

Cambrian System.—This system is largely developed in Wales; hence its name. The rocks are chiefly sandstones, flagstones, and grits, and are 18,000 or 20,000 feet in thickness. The fossils are mostly of a marine character, including shell-fish and zoophytes. In some of the sandstones belonging to this system may be seen the ripple-marks left by the tide, and the distinct impression of rain-drops. Rocks belonging to this system have been found in Wales, Cumberland, north-west of Scotland, Ireland, Bohemia, and in Canada. The scenery in Cambrian districts is generally bold, rugged, and picturesque; but the soil is often sterile and unproductive. The strata often contain the ores of iron, copper, silver, lead, and tin.

Silurian System.—The rocks belonging to this system are also largely developed in Wales. They are met with also in Cumberland, Scotland, and in different parts of Ireland. They consist of roofing slate, flagstones, sandstones, limestones, and conglomerates, which speak of rivers carrying down mud, of sandy shores, gravel beaches, and deep seas. The fossils are numerous, and include all the lower forms of marine life: zoophytes, radiata, mollusca, and crustacea; and in the upper beds of the system was discovered, in 1859, the oldest known remains of a fish with a backbone. It is said to have been allied to the sturgeon, and has been named *pteraspis*. In this system, also, we find traces of sea-weeds, and of land plants allied to the club-mosses. The rocks of the Silurian system are rich in ores of mercury, gold, and silver. The scenery is generally very beautiful, being varied with hill, dale, ravine, and glen.

Devonian, or **Old Red Sandstone.**—This system is well developed in Devon, as well as on the borders of Wales and in the central parts of Scotland. The strata are partly of marine and partly of fresh-water origin, and consist chiefly of sandstone rocks, alternating with shales, conglomerates, and limestones. Some of the sandstones

have a deep red tint, and owe their colour to the presence of iron in the water in which they were deposited. In this system we find the first decided evidence of land vegetation, which consists of the remains of plants allied to the bulrush, equisetum or horse-tail, and tree-ferns. The characteristic fossils of the system, however, are fishes of various kinds, but all covered with hard enamelled scales or bony plates. The minerals are not of great importance in Old Red Sandstone districts, consisting chiefly of flagstones and building-stones. The scenery is often flat and tame, or gently undulating, showing that igneous action has not been so great as during the deposit of preceding strata. The soil is, however, generally well adapted to agriculture.

Carboniferous System.—This is, perhaps, one of the most important of all the geological systems. Its strata consist of shales, sandstones, clays, and limestones; and along with these are thick seams of coal. The coal-measures speak of an extraordinary abundance of vegetation, and among the fossils we find traces of gigantic pines, large tree-ferns, reeds, and club-mosses. These plants all indicate a moist and equable climate, which might be owing, in some degree, to a different arrangement of sea and land. Among the fossil animals may be traced all the lower forms of previous systems, together with the remains of reptiles and insects. At Saarbruck were discovered, in 1854, among other remains, traces of a beetle, remains of white ants, and a distinct impression of the wing of a grasshopper. In this same neighbourhood, also, were discovered, seven years previously, the first skeletons of distinct air-breathing animals. They appear to have resembled lizards, and have received the generic name of *archegosaurus*. In the coal-fields of Nova Scotia the *dendrerpeton* and other reptiles have been discovered of still more ancient date.

Most of the valuable coal-fields in different parts of the world belong to the Carboniferous system, and it is largely developed in Great Britain. In Ireland, mountain limestone is abundant, but the coal-measures are almost entirely

wanting. Besides coal, several other valuable minerals are associated with the Carboniferous system. Among these may be mentioned ironstone, ochre, copperas, paraffin, fire-clay, good building-stone, limestone, and marble. The mountain limestone is, in England, the usual repository of the ores of lead, zinc, and silver. The scenery, with the exception of some limestone districts, is generally tame and unpicturesque; and the soil is often cold and only moderately fertile.

Permian System.—The principal rocks belonging to this system are sandstones and yellowish magnesian limestones. The fossils are similar to those of the last system, but are by no means so abundant. It has been pointed out that all the fishes found in the magnesian limestone and in the older formations are *heterocercal*—that is, the lobes of their tails are unequally divided, and the backbone is prolonged in the upper lobe; while most of the fishes found in the more recent systems, and nearly all those which exist at the present day, are *homocercal*—that is, the lobes are equal; the shark and sturgeon, however, are heterocercs. The Permian system seems to mark also, in some other respects, a change in the character of the fossils. There is an absence of that profusion of corals and encrinites which characterized the mountain limestone, and of the trilobites which were so abundant in the Silurian period. Hence geologists generally look upon the Permian system as marking the close of what is termed the *Palæozoic* period, or period of ancient life. The system obtains its name from Perm, a government in Russia, where the characteristic rocks abound. It is not largely developed in England, but clings like a fringe round many of our coal-fields. The minerals associated with it consist of excellent building-stones, limestone, gypsum, and copper. The scenery generally is tame and flat, but the soil produces rich and verdant pastures.

Triassic System.—The word *triassic* means triple, and the system is so called because it contains three well-defined divisions—keuper, muschelkalk, and bunter. The second division, which consists of beds of gray limestone,

is wanting in England, but all three divisions are met with in Germany. The keuper consists of red, bluish, greenish, and whitish clays or marls, holding gypsum generally, and sometimes, as in Cheshire, rock-salt. Interstratified with these marls are certain gray and whitish sandstones. The bunter sandstein (variegated sandstone) consists chiefly, as the name implies, of variously-coloured sandstones. Fossils are much more numerous than in the Permian system, and occasionally, as at Richmond, in North America, the vegetation has been sufficiently abundant to produce coal. Among animals we find distinct traces of reptiles, and some footprints found in the sandstone rocks in the valley of Connecticut have been identified as belonging to a gigantic bird, which was probably four times the size of an ostrich. In this system, also, we find the earliest remains of mammals. In 1847 the tooth of a small animal, which has been termed *microlestes* (little wild beast), was discovered near Stuttgart; it is supposed to have been a marsupial. The remains of a similar animal were subsequently found in the Chatham coal-field (North Carolina) belonging to this system, and still more recently (1860) the jaws and detached teeth of a mammal were found near Bristol. The Triassic system is well developed in England, and runs from the mouth of the Tees to the junction of the Avon and Severn, and then northwards so as to include the county of Cheshire and a part of Lancashire. The characteristic mineral production is rock-salt. The scenery in general is rather tame, and the soil better suited for pasture than for mixed husbandry.

Oolitic System.—The word oolitic means eggstone, and is applied to this system on account of the concretionary grains, resembling the roe or egg of a fish, which compose many of its limestones. The system is usually divided into the *Lias* and *Oolite*, and it consists of alternate bands of clay, sandstone, and limestone, following each other in the same order. The distinctive fossils are those of huge reptiles belonging to the lizard family, [illegible] the *ichthyosaurus*, *plesiosaurus*, and *pterodactyle*. [illegible]rmer belong to the Lias, the other to the

Oolite. In this division, also, is found the oldest fossil bird that has been met with. The skeleton was found at Solenhofen in 1862, and, with the exception of its head, was almost entire. It was named by Professor Owen the *archæopteryx* (ancient wing), and is now in the British Museum. There are also in this system abundant remains of marsupial animals. Fossil plants are also very abundant, including coniferæ allied to the yew and cypress, and leaves belonging to plants resembling the lily, pine-apple, and aloe. At Brora, in Sutherlandshire, there is a coal-field belonging to this system. Jet, a lustrous kind of coal, is met with among the Oolitic strata of Yorkshire. The Oolitic system stretches in a broad belt from the North York moors to Lyme Regis, in Dorset. It is not met with either in Scotland or Ireland to any great extent, but is well developed in France, Germany, Switzerland, and North America. As the rocks are very abundant along the flanks of the Jura Mountains, the term *Jurassic* is sometimes applied to this system. The minerals are of considerable importance, including building-stone, marble, jet, and fuller's earth. The scenery in Oolitic districts is, upon the whole, varied and pleasing, and the soil dry and fertile.

Cretaceous System.—This is so called on account of the thick beds of chalk (*creta*) which it contains; the other components are chiefly sands and clays. It is generally divided into two parts—the Upper Cretaceous, and the Lower Cretaceous or Neocomian. The former comprises the chalk, upper greensand, and gault; the latter, lower greensand and Wealden. All these, except the Wealden, are of marine formation. The *Wealden* is estuarine; hence the fossils are quite distinct from those of the other divisions of the system, and by some writers it is classed with the Oolites. The Wealden formation forms a broad tract in the counties of Surrey, Sussex, and Kent, and can be traced across the Straits of Dover into France. It doubtless formed at one time—before the British Islands were separated from the Continent—the estuary of a large river.

Leaving out the Wealden, we find that the fossils of the chalk are chiefly of marine origin, comprising sponges, corals, fishes, and reptiles. The formation extends in a broad belt from the north of Ireland to the Crimea, and from Sweden to Bordeaux. All this broad tract must at one time have been occupied by a deep sea. In England the Cretaceous system is exhibited in the various chalk ranges. The minerals are chiefly chalk and flint, with, occasionally, fuller's earth and an inferior kind of building-stone. The Chalk Downs afford excellent sheep pasture.

Tertiary System.—We have already stated that the Permian system is looked upon as closing the Palæozoic period; in like manner the Cretaceous system closes the *Mesozoic* (middle life) period; while the Tertiary system introduces the *Cainozoic* (recent life) period. Sometimes the systems themselves are grouped into three similar divisions, known as Primary, Secondary, and Tertiary. The Primary and Secondary groups have been subdivided into the systems already described. The word Tertiary, however, still retains its place as the name of a system; but it has been found necessary to subdivide it into the Eocene, Miocene, and Pliocene groups, according to the characteristic shells of each. It is in the Tertiary period that we first meet with shells *identical*, so far as we can discover, with those existing at the present day. At first these shells are very scarce, but they become more and more numerous, until, in the Pliocene strata, they actually outnumber the shells that have since become extinct. It is on these facts that the subdivisions have been made. The word *Eocene* means "dawn of the recent," and in this group existing shells first appear; *Miocene* (less recent) implies that the number of existing species is less than that of the older forms; *Pliocene* (more recent) implies that the recent forms predominate. Professor Ramsay states that, as a matter of fact, no one Eocene shell is now recognised as belonging to any existing species; the term applied to the group, however, is a convenient one, and is still retained.

In the Tertiaries we first meet with undoubted evidence of exogenous or deciduous trees, such as the oak, elm, and beech; while among animals we have species of every existing order except man. It is during this period, also, that we first meet with traces of that geographical distribution of animals which now exists. In the older systems, so far as has been ascertained, the fossils were almost identical, in whatever part of the world they were found. In the Tertiaries, however, the fossils found in South America are allied to its present sloths, ant-eaters, and armadilloes; while in Australia we meet with fossils akin to the marsupial family. Europe was at this time inhabited by gigantic pachyderms, including elephants and rhinoceroses, and abundant traces of these have been found in the British Islands. It would appear, indeed, that during the Eocene period Central Europe enjoyed an almost tropical climate; but by degrees the temperature was gradually lowered, until, at the close of the Pliocene age, the Glacial period commenced.

The Tertiary deposits generally exhibit an irregular succession of clays, limestones, marls, sands, and grits,

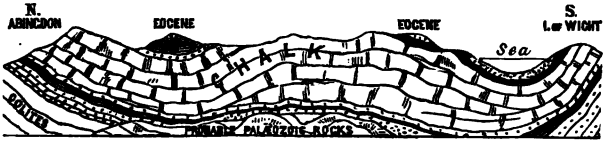


FIG. 2.—Section of rocks from Abingdon to Isle of Wight, showing "basins" occupied by Tertiary deposits.

and, so far at least as Europe is concerned, the deposits occupy well-defined tracts or basins; and hence we speak of the London basin, the Hampshire basin, the Paris basin, and the Vienna basin. The industrial products of the system are building-stone and marbles of various qualities, pipe and potter's clays, and gypsum. Lignite, or brown coal, is also worked in many districts, and amber, a fossil gum, is obtained from the lignite beds. The scenery in England is generally rather tame, but on the Continent the

Tertiary districts are often varied and picturesque. The soil is generally fertile.

Among the mountains of Auvergne, in the south of France, may be distinctly traced the cones and ancient lavas of volcanoes which were in full activity during the Tertiary period. The basaltic columns of Fingal's Cave and Giant's Causeway are the products of active volcanoes that existed during the Miocene period. It is said by geologists that the great mountain-chain which extends from the Himalayas to the Pyrenees has been raised since the commencement of the Eocene age, and Sir Charles Lyell informs us that the whole cone of Etna, 11,000 feet in height, and about 90 miles in circumference at the base, has been slowly built up by the material erupted by the volcano since the Pliocene age.

Glacial Period.—The close of the Tertiary period was accompanied by intense cold, probably due to astronomical causes. The tops of the mountains of Wales, Cumberland, and the Highlands of Scotland were covered with glaciers. Traces of these can still be seen in the mountain valleys of Cumberland and Wales, as well as in various parts of Scotland. After a time the whole of Northern Europe and part of North America seem to have been gradually submerged. The glaciers, now reaching the level of the sea, broke off and formed immense icebergs, which floated southward and spread their drift and boulders over the submerged plains. Traces of these icebergs are discernible throughout Northern Europe, and may be recognised in England as far south as the valley of the Thames. After a time—how long it is impossible to say—the land slowly emerged from the sea, the temperature gradually grew milder, the glaciers diminished in size, and in many places totally disappeared, and the distribution of land and water took its present form.

CHAPTER IV.

Volcanic Action.

In the brief sketch of geological systems mentioned in the last chapter we more than once referred to the fact that there were distinct traces of former igneous action in the British Islands, and that the basaltic rocks of Giant's Causeway and Fingal's Cave were the products of ancient volcanic activity. Before considering the cause of this igneous action, it may be well to give a brief sketch of the present distribution of earthquakes and volcanoes, together with some of the phenomena which usually accompany them.

Earthquakes.—The whole west coast of South America is exposed to violent earthquakes, and also the northern shore almost as far as the mouth of the Amazon. The remainder of the continent, however, is remarkably free from disturbance. The coast of Chili experienced a destructive disturbance in 1822. The shock was felt simultaneously through a distance of 1200 miles from north to south, and Valparaiso and other towns were greatly injured. On the morning after the shock it was seen that the whole coast in the neighbourhood of Valparaiso had been raised three or four feet above its former level.

Central America, including the West India Islands, is a centre of great volcanic intensity. In March 1873 San Salvador, a city of 40,000 persons, was totally destroyed. Fortunately the inhabitants, having been warned by a previous shock of less intensity a few days before, had deserted their dwellings, and hence the loss of life was not great. The West India Islands and the Gulf of Mexico belong to an earthquake area which embraces also the Alleghany Mountains and the east coast of North America

as far as Nova Scotia. The whole west coast of the continent is also subject to earthquakes, and there is a remarkable area in the interior, including the upper valleys of the Yellowstone and Columbia rivers. The Yellowstone has its source in a beautiful lake, which is surrounded by volcanic rocks. The river leaves the lake at its northern extremity, and flows for miles through a valley filled with geysers, hot springs, and mud volcanoes. There are no active volcanoes except these; and the igneous forces which appear to have been in full activity towards the close of the Tertiary period now seem to be dying out.

The Aleutian Islands, and the groups which fringe the east coast of Asia, are intensely volcanic. In the Eastern Archipelago we meet a band which, on the one hand, is continued through New Guinea, New Britain, and New Ireland to New Zealand; and, on the other, to Sumbawa, Java, and Sumatra. Australia is remarkably free from earthquakes, and Africa almost so. Slight shocks, however, are occasionally felt in Egypt, Morocco, and Cape Colony. Indeed, the three southern continents, if we except the west coast of South America, present a marked contrast to the three northern ones in their comparative freedom from the effects of volcanic action.

An earthquake area of great intensity extends across the south of Asia and through the Mediterranean, stretching from the Bay of Bengal to the Azores. A similar district, though of less intensity, stretches northwards from the Himalayas, and includes the Thian Shan and Altai Mountains. In Western Europe an earthquake band extends through Spain, France, Holland, and the British Islands to Iceland. The terrible earthquake which took place at Lisbon in 1755 was most destructive in its effects. A violent shock threw down the greater part of the city, and in six minutes 60,000 persons perished. According to Humboldt, the area over which the effects of this earthquake were felt was four times greater than the whole of Europe. The shock was felt in the Alps, on the coast of Sweden, in Canada, the West Indies, and Morocco. In Loch Lomond the water rose and then subsided below its usual

level. The temperature of a spring at Luchon, in the Pyrenees, was suddenly raised 70°, or changed from a cold spring to one of 122° Fahr., a heat which it has since retained; while the hot springs at Töplitz, in Germany, were at first dried up, and then returned, inundating everything with their discoloured water.

It is generally admitted that an earthquake is the result of some violent and sudden explosion, and that this explosion is probably caused by steam. Water finds its way to great depths, and becomes very often heated to a considerable temperature. Now if, through the cracks and crevices which abound in the crust of the earth, or, by percolating through the rocks themselves, it finds its way into the neighbourhood of some internal fire, it will at once be converted into steam; and steam, when exposed to heat, becomes as explosive as gunpowder. An explosion or series of explosions is the inevitable result, and the effect of the concussion is spread all round in a series of earth-waves. The force generated by the explosion does not operate, however, in a horizontal direction, like a wave caused by a pebble on the surface of a pond; for at every point of the surface, except that immediately above the focus of the shock, it comes up obliquely from below. The shock, indeed, is propagated in all directions from the centre of disturbance in a series of spherical shells, and, of course, the movement will be first felt on the surface at a point perpendicular to the focus. This point is called the *seismic vertical* (Gr. *seismos*, an earthquake). The vibration will reach other points of the surface a few seconds later, according to their distance from the focus. The points on the surface reached simultaneously by the earthquake-waves would, of course, form a series of concentric circles; these are called *coseismal circles*, and the individual points *coseismic points*. A section of the spherical shells—perpendicular to the surface—would also, it is evident, give us a series of coseismal circles.

Mr Mallet, who has devoted great attention to the study of earthquakes, endeavoured to determine the position of the focus of an earthquake which took place in the neigh-

bourhood of Naples in 1857. By a careful examination of the disturbed surface he first sought to find the seismic vertical; and that point being determined, his next step was to ascertain the angle at which the wave emerged at different points on the surface. The point where the oblique lines met the perpendicular dropped from the seismic vertical gave the focus; and the conclusion arrived at was that the focus was not at a greater depth than seven or eight miles. Of course, the great difficulty in making such a calculation as this is that the crust of the earth is not homogeneous. It is composed of a great variety of rocks differing in density and elasticity, and the waves propagated by the explosion would, therefore, in some cases be checked and reflected, and neither the direction nor the velocity would be uniform. At best, therefore, Mr Mallet's calculation can only be an approximation; still, it is a very valuable one, and was probably not far from the truth. He thinks that in no case do the shocks which produce earthquakes come from a greater depth than thirty-five miles.

Though the seismic force—as the cause producing the earthquake is termed—acts in the way we have described, still, to the inhabitants living in any place visited by an earthquake, the earth-waves would appear to spread out on all sides from the place where the shock was most intense, in a horizontal manner, and the undulations thus produced would diminish in size as they receded from the seat of the explosion. Earthquakes are sometimes classed as perpendicular, undulatory, and horizontal. The first, of the nature of a sudden upheaval, is felt at or near the centre of the disturbed area—in other words, near the seismic vertical. The second is a mere undulation caused by the earth-waves, and is less intense the farther it is removed from the centre of disturbance. The third form of earthquake is exceptional in character. It consists of a horizontal motion forward and back again, producing an effect similar to what would be caused by a vorticose or whirling motion. These horizontal movements are very destructive.

If the focus of the earthquake be beneath the bed of the ocean, the earth-wave, travelling quicker than the water-wave, reaches the shore first, and hence the sea seems to retire. Shortly afterwards the ocean-wave rushes in, and often causes immense destruction. This was the case in the earthquake at Lisbon. The sea at first retired, and laid dry the bar at the mouth of the Tagus. It then rolled in, rising fifty feet above its former level, and a huge wave washed away hundreds of the panic-stricken inhabitants. A similar phenomenon was observed in the series of earthquakes that visited the coast of Peru in 1868. At Arica the sea at first seemed to retire, and all the vessels in the bay were carried out into the ocean, anchors and chains snapping like pack-thread. A few minutes later the outward current was stopped by a huge wave, about fifty feet high, which came in with a mighty rush, carrying all before it. Several vessels were wrecked; but an American gunboat, the *Wateree*, was lifted up by an immense billow and carried half a mile inland. There she was landed among the sand-hills, perfectly upright, without a scratch, and not a man hurt.

Both the earth-wave and the water-wave are liable to be broken and deflected by obstacles with which they come in contact; for some portions of the earth's crust are better media for transmitting the undulations than others. Hence, probably, those horizontal movements to which reference has been made.

Volcanoes.—Volcanoes and earthquakes have precisely the same origin. When an explosion takes place in the interior of the earth, and the molten matter, finding a vent, is poured out at the surface or beneath the waters of the sea, a volcano is formed. If there be no such vent, the ground will be upheaved and rent, and the shock will produce the vibration known as an earthquake. Volcanic mountains are known by the conical form of their summits; and the opening through which the erupted matter is ejected is called a *crater*, from its hollow, bowl-like shape. There has been considerable difference of opinion as to the origin of volcanic cones, but it is now generally

agreed that they are caused by the accumulation of ashes, lava, and other material thrown up by the volcano itself. An eruption generally begins with a dense column of steam issuing from the crater and spreading out like a cloud. Then masses of rock and molten matter are ejected with tremendous violence; after which lava begins to flow, and the whole generally terminates with a shower of dust and ashes.

If we notice the distribution of volcanoes, we shall find, as we might expect, that they occur within the regions visited by earthquakes, but are, of course, less widely distributed. The Pacific Ocean is literally fringed with volcanoes. Commencing with Graham's Land, in the Antarctic Ocean, where the active cone of Erebus reaches a height of 12,000 feet, we cross to Tierra del Fuego; and now commences that magnificent range of volcanic summits which runs through the Andes, Central America, and the Rocky Mountains. In South America may be mentioned Aconcagua, the loftiest mountain in the New World; and Cotopaxi, Chimborazo, Antisana, Pichincha, and Tunguaragua, which surround the city of Quito. *Cotopaxi*, which stands 19,000 feet above the sea-level, is said to have thrown out flames 3000 feet above the brink of its crater; but this appearance was probably due to the reflection of the red-hot lava on the ascending column of smoke.

In Central America we have a double chain of volcanoes —one passing through the West India Islands, and the other through Guatemala and Mexico. In Guatemala we meet with the cone of *Coseguina*, where a remarkable eruption took place in 1835. Eight leagues to the south of the mountain the ground was covered with ashes to the depth of three yards and a half, destroying woods, dwellings, and thousands of cattle. Ashes also fell at Kingston, in Jamaica, having been carried by an upper current in a direction contrary to the regular trade-wind.

Mexico is the seat of intense igneous activity. About three-fifths of the country is occupied by a table-land called the pleateau of Anahuac. The most remarkable tract in

this elevated region is the Plain of Malpais, which is surrounded by ridges of basaltic rocks, and crossed from east to west by five active volcanoes—Tuxtla, Orizaba, Popocatepetl, Jorullo, and Colima. In the beginning of 1759 the space now occupied by the cone of *Jorullo* was covered by fertile fields of sugar-cane and indigo. In the month of June hollow sounds of an alarming nature were heard, and earthquakes succeeded each other for two months. At the end of September flames issued from the ground, and fragments of burning rocks were thrown to prodigious heights. Six volcanic cones, composed of scoriæ and fragmentary lava, were formed on the line of a chasm which ran from north-east to south-west. The least of these cones was 300 feet in height; and Jorullo, the central one, was elevated 1600 feet above the level of the plain. It sent forth great streams of lava, and its ejections did not cease until February 1760.

North of Mexico there are one or two active volcanoes in the peninsula of California. Mount Hood and St Helen's, near the mouth of the Columbia, are also volcanic; and we may mention also Mount St Elias, in Alaska, which attains an elevation of 18,000 feet. From Mount St Elias a chain of volcanic summits runs through the Aleutian Islands to Kamtchatka, where the cone of Klutchew rises up from the sea to an elevation of 15,000 feet. The chain is continued through the peninsula of Kamtchatka and the Kurile Islands to Japan. It then extends by Loo Choo and Formosa to the Philippine Islands, and thence to the Celebes. Here one branch turns to the south-east, and is continued through New Guinea and New Hebrides to New Zealand and Victoria Land, thus completing the circuit of the Pacific; while the other is continued in a westerly direction through Sumbawa and Java to Sumatra and the Bay of Bengal.

There is no spot of the same size upon the globe which is the seat of such intense igneous activity as Java. A ridge of volcanic summits forms the central crest of the island, and ends towards the east in a series of thirty-eight distinct cones. They stand on a plain but little elevated

above the sea, and are covered with thick vegetation. Some are extinct, or only emit smoke; from others issue immense quantities of sulphureous vapour; one has a large crater filled with boiling water; and a few have sent forth fierce eruptions in modern times. There is one crater in this part of the island which contains a lake strongly impregnated with sulphuric acid, from which issues a river which supports no living creature, nor can fish exist in the sea near its mouth. The celebrated *Poison Valley* of Java is another extinct volcano. It is about half a mile in circumference, and the bottom is filled with exhalations of carbonic acid gas. Every living thing which enters the valley is instantly suffocated; and the ground is covered with the carcasses of tigers, deer, birds, and even the bodies of men.

It is a remarkable circumstance that no active volcanoes are found at any great distance from the sea. Pe-shan and Ho-tcheou, in the Thian Shan Mountains, which are sometimes mentioned as exceptions to this statement, have been shown by recent travellers to possess none of the characteristics of volcanic summits. Further west, on the southern shore of the Caspian Sea, we meet with the smoking cone of Demavend, which rises about 18,000 feet in height, and is a conspicuous landmark for sailors on the Caspian. When we reach the shores of the Mediterranean we meet with several active cones. In the Grecian Archipelago is the submarine volcano called *Santorin*. The rim of the crater appears above the surface of the water as two islands, the larger one, named Thera, forming more than two-thirds of the circuit. The exterior circumference of the rim is about thirty miles, and the diameter of the enclosed gulf about six miles. If this gulf could be drained, a bowl-like cavity would appear, with walls 2000 feet high in some parts, and nowhere less than 1200 feet. Three small islands in the gulf would then appear as the summits of a huge mountain. An eruption took place here in 1866, when a new island was thrown up.

Vesuvius, the only active volcano on the continent of Europe, is celebrated for the eruption of A.D. 79, when the

cities of Pompeii and Herculaneum were buried in ashes. It has shown signs of vigorous activity during the present century. *Etna* has also been a very active volcano both in ancient and modern times. Its huge cone, nearly 11,000 feet in height, with a base ninety miles in circumference, has been entirely formed, as we stated in the last chapter, since the close of the Tertiary period. The small volcano of *Stromboli*, in the Lipari Islands, is in a state of almost constant activity. On the other hand, a lofty volcano like Cotopaxi has only about one eruption in a century. It was noticed that at the commencement of the Calabrian earthquakes in 1783 Stromboli smoked less, and threw up a less quantity of inflamed matter, than it had done for several years previously.

The shores of the Atlantic contrast with those of the Pacific in being remarkably free from volcanoes; on the other hand, most of the islands are volcanic. Besides the West Indies, we may notice the Canaries, with the peak of Teneriffe; the Azores, with the summit of Pico; and the island of Iceland. From records which have been carefully kept, it appears that since the commencement of the twelfth century there has never been in Iceland an interval of more than forty years without either an eruption or a great earthquake; and some of the eruptions of Hecla have continued for six years. A tremendous eruption of *Skaptar Jökul* took place in 1783. The torrent of lava filled up the valley of a river, as well as the bed of a deep lake, and then spread over the country with a breadth, in some cases, of twelve to fifteen miles. The eruption lasted two years; and it has been calculated that the quantity of lava thrown out surpassed in magnitude the mass of Mont Blanc. No less than twenty villages were destroyed, and more than 9000 persons perished.

The largest active crater in the world is that of *Kilauea*, in the island of Hawaii, one of the Sandwich group. Hawaii is triangular in shape, and about the size of Sicily. It contains three volcanic summits, of which Mauna Loa, 13,700 feet in height, is best known. Mauna Loa has two craters, one at the summit, and the other, Kilauea, about

8000 feet below the summit on the western side. It is about seven miles in circuit, and 1000 feet in depth. The crater never ejects steam or ashes, but the lava, issuing from a multitude of cones, sometimes fills the vast area to a height of several hundred feet. An hotel has been built on the edge of the crater by an enterprising American, for the accommodation of visitors.

We have already stated that during an eruption various gases are emitted from a volcano. These are mainly carbonic acid, oxygen, hydrogen, nitrogen, and carburetted hydrogen. At first, and while the eruption is active, hydrogen is present in large quantities. Afterwards, as the temperature lowers, the hydrogen diminishes, but the carbon and nitrogen increase in quantity. Towards the close of the eruption the hydrogen disappears, and carbonic acid gas forms about 90 per cent. of the whole. The fumaroles, or smoking vents, which abound both in the crater and the lava streams during an eruption, emit other substances. At first the alkaline products prevail, but by degrees, owing to diminished temperature, the acids preponderate. Soda, potash, sulphur, and lime in small quantities are common; and traces of metals, such as copper and lead, have been detected. Immediately after the lava has ceased to flow, and while it is still red-hot, various chlorides form a bright-coloured band within and near the crater; and sulphates, chiefly of lime, form a whiter zone. Alum, in various forms, is always met with, and carbonate of soda has been observed in crevices of recently cooled lava.

In many volcanic districts may be traced a certain amount of subdued activity. This is chiefly displayed in fumaroles, eruptions of boiling water, and mud volcanoes. The term *fumarole* is applied not only to the jets of smoke and gases emitted from the crater and lava during an actual eruption, but also to the issues of vapour long after the eruption has ceased. The presence of sulphur in large quantities converts the fumarole into a *solfatara*, where thick deposits of sulphur in a crystalline form are often found. Mud volcanoes, or *salses*, are low conical hills that

have been formed by the eruption of mud and water. They are very numerous in the Crimea and along the southern slope of the Caucasian Mountains. They have been met with also in China, Java, and Mexico; and there are some well-known examples in Italy and Sicily. In all cases these salses represent the declining stage of volcanic activity.*

We have already stated that the causes which produce volcanic outbursts are identical with those that give rise to earthquakes; that in both cases there is an explosion in the interior of the earth, and that this explosion is probably caused by steam. Upon this subject most geologists are agreed; but there is a difference of opinion respecting the source of internal heat which produces the steam.

Mr Mallet offers a simple explanation, which is very generally received. He believes that the friction of the rocks, caused by shrinkage in different parts of the earth's crust, is a sufficient and satisfactory explanation of the occurrence of the high temperature necessary to produce volcanic action. If, as is now generally believed, the earth was once in an incandescent state, and has gradually cooled down, it would diminish in bulk as it lost its temperature. The process is still going on; and Mr Mallet has calculated that one-fourth of the amount of contraction now actually taking place would suffice to account for the entire seismic energy of the earth. We have here an example of motion being converted into heat. The earth cools, and therefore contracts; the shrinkage of the crust produces motion, and the motion causes the heat which melts rocks and produces earthquakes. It would appear, also, if this theory be correct, that, contrary to the notion very generally held, volcanoes and earthquakes are the *effect* of a movement in the earth's crust rather than the cause of such movement.

Areas of Elevation and Subsidence.—We have various examples, in different parts of the earth, of a gradual elevation of its surface; in other parts we have areas of sub-

* Ansted: *Physical Geography.*

sidence. The raised beaches which we see around our shores prove that the general level of the land has been raised; the long stretches of sand, which in many places are now above high-water mark, prove the same thing. We have already referred to the east coast of Scotland. We have evidence, also, to prove that the northern shores of the Baltic have been raised about twenty inches since the commencement of the present century. A similar upraising has been observed in Siberia, at Spitzbergen, and on both sides of Smith Sound, at the head of Baffin's Bay. There are also tracts on the coast of Asia Minor, on the northern and eastern shores of Africa, and on the northern shore of the Gulf of Mexico, where elevation is taking place; and to these instances we may add the whole of the west coast of South America.

On the other hand, there are in many places distinct evidence of subsidence. There is a large tract in the Pacific, extending from Marshall Islands to Low Archipelago,—a distance of 4500 miles,—where the bed of the ocean is slowly sinking. This is proved by the depths to which the coral reefs extend. We have before stated that the living coral cannot exist at a depth exceeding 20 or 30 fathoms, yet coral reefs are often found at five or six times that depth. Another area of subsidence is the Coralline Sea, to the east of Australia; and extensive areas of depression also occur in the Chinese Sea and in the Indian Ocean. The coast of Europe from the mouth of the Vistula to that of the Seine seems also to be slowly sinking, and there is a similar tract on the south-west coast of Greenland. Coming to our own island, we also meet with evidences of subsidence. In the Fen district round the Wash, the remains of a forest have been found about six feet below the level of the present surface, with the trunks of trees standing for the most part erect. Similar forest beds have been found at Walthamstow, at Plumstead, and in Westminster.

Now, though volcanic action might explain the occurrence of areas of elevation, it does not account for areas of subsidence; and the explanation is probably to be sought for

in the secular cooling of the earth. It follows from the very nature of aqueous rocks that the strata ought, unless they have been disturbed, to be found more or less in a horizontal position; but more frequently the rocks are inclined at various angles, and sometimes bent into curves more or less perfect. (See Fig. 2, p. 43.) This is a fact well known to geologists, and they have termed the curves synclinal and anticlinal, according as they are concave or convex. In the sea cliffs near St Abb's Head we have a very striking example, and at least sixteen curves or bendings can be seen in a distance of six miles. The explanation of these and similar foldings is, that the strata, after being deposited horizontally, have been exposed to lateral pressure; and this pressure is doubtless caused by the secular cooling of the earth. The radiation of heat will cause the earth to diminish in bulk; the rigid crust, in its efforts to accommodate itself to the lesser nucleus, would become crumpled again and again. The downward pressure of certain parts would act as a lateral force on the neighbouring strata, and cause its curves and foldings. But this shrinkage has also another effect: the downward pressure, as we have already stated, causes motion, the motion produces heat, and this heat manifests itself in seismic and volcanic activity.

CHAPTER V.

Surface of the Earth.

If we glance at a map of the world, or examine an artificial globe, we are at once struck with the preponderance of water upon the earth's surface. Out of a total area of nearly two hundred million square miles, fifty-two millions, or about one-fourth only, is occupied by land. Of this land, again, three-fourths lie to the north of the equator. This is in itself a curious fact, but it is not all. Almost the whole of the land is really grouped on one side of the globe, so that not more than one twenty-seventh part has land opposed to it on the opposite side. If, in an artificial globe, we take Falmouth as a centre, we find that it is the pole of a hemisphere which contains forty-nine millions out of the fifty-two million square miles of land. Falmouth may, therefore, be taken as the centre of the terrestrial hemisphere of the globe; and a point in New Zealand is the centre of the aqueous hemisphere.

Form of Continents.—If we now consider the forms of the great land masses, we are struck with the fact that they are all more or less triangular in shape; and if we descend to details, we see the same idea carried out in the peninsulas which fringe the borders of the northern continents. Another curious fact is that most of the peninsulas, in whatever part of the world we meet with them, point to the south. The great land masses may be grouped into two sets of three each: the northern continents, embracing Asia, Europe, and North America; and the southern continents, embracing South America, Africa, and Australia. Looking merely at the outline of these continents, we find the northern continents differing from

the southern masses in one or two important particulars. The northern continents are all much indented; each terminates on the south in three projections; and each has an archipelago of islands attached to it. In Asia we have Further India, Hindostan, and Arabia, with the East Indian Archipelago. In Europe we have the peninsulas of Greece, Italy, and Spain, with the Grecian Archipelago. In North America we have the peninsula of California, the isthmus of Panama, and the peninsula of Florida, with the West India Islands.

The southern continents, as a whole, are remarkable for their compact outlines, and for the absence of numerous indentations. They differ from the northern continents, also, in the fact that they terminate in one point instead of three, and that each has a large island near its southern extremity. Thus Tierra del Fuego lies at the southern extremity of South America; Madagascar near the southern point of Africa; and Tasmania at the southern extremity of Australia. It has also been remarked that each of the southern continents has a large bulge or deep bend on its western side: it is sufficient to mention the Bight of Australia, the Gulf of Guinea, and the large bend on the west side of South America.

As every foot of dry land was once beneath the water, so we might expect that the beds of the great oceans were once dry land. Many geographers see in the coral islands of the South Pacific evidence of an ancient continent which has sunk below the ocean, and some naturalists look upon the *Globigerina ooze* of the North Atlantic as the chalk beds of a future age. Sir Charles Lyell seeks for an explanation of the different climatic changes that have taken place in different parts of the globe during geological ages in different distributions of land and water that have from time to time prevailed upon the globe. On the other hand, some geologists think that the distribution of land has never differed very much from what it is at present. In a paper read before the Royal Geographical Society, Professor Geikie expresses his belief that the great ocean

beds have always existed, and that the great continents have for the most part occupied the same positions as they do now. He supports his opinion by two statements: (1.) That the sedimentary rocks are shallow deposits formed out of the waste of the land, and always laid down near land; (2.) That the deposits met with at the bottom of the great ocean beds have no real analogy with the materials out of which sedimentary rocks have been formed. We cannot say that to us his arguments are conclusive, and it will be sufficient if the reader bear in mind that upon this subject geologists are not agreed.

If now we turn our attention to the elevation or contour of the continents, we shall find one or two points of interest. The six continents seem to be constructed on three different plans. In Europe and Asia the chief mountain ranges run east and west; in the two Americas, north and south; while in Africa and Australia the mountain chains lie round the coast, leaving a basin-like depression in the interior. It is interesting to notice that the whole three types of structure are met with in the British Islands. In Scotland the Grampians and Lowthers run east and west; in England the chief ranges have a direction from north to south; in Ireland the mountains lie round the coast.

Contour of Land.—Turning now to the four continents first mentioned, we find that they all rise gradually from the sea-shore to the interior, to some line of highest elevation. This line of elevation is never in the centre, but nearer to one side of the continent than the other. In Asia the culminating line is the Himalayas; in Europe, the Alps; in America, the Andes and Rocky Mountains. Hence result two slopes, unequal in length and inclination. Another fact worthy of notice is, that the general elevation of the surface of these continents goes on increasing from the poles to the equator. Thus the plateaus of Thibet and Pamir, belonging to the system of the Himalayas, are the loftiest in the Old World; while the plateaus of Cuzco, Titicaca, and Pasco, which lie within the tropics, between parallel ranges of the Andes, are the highest table-lands of the western hemisphere. The culminating point in the Old

World is Mount Everest, which attains an elevation of 29,000 feet in the parallel of 27° N.; the culminating point in the New World is the summit of Aconcagua, which reaches the height of 24,000 feet in the parallel of 32° south. This disposition of the loftiest mountains and plateaus in the neighbourhood of the tropics has considerable effect upon the general climate of the globe, and tends to increase the amount of habitable land.

Towards the conclusion of the last chapter we referred to the secular cooling of the earth as being the probable cause of the various areas of elevation and subsidence met with in different parts of the earth's surface. Professor Ramsay thinks that to the same cause we may assign the origin of the great mountain chains. "By what means," he asks, "were masses of strata, many thousands of feet thick, bent and contorted, and often raised high into the air, so as to produce existing scenic results by affording matter for the elements to work upon? Not by igneous pressure from below raising the rocks, for that would stretch instead of crumpling strata in the manner we find them in the Alps, Norway, and the Highlands, or in less degree in Wales and Cumberland; but rather because of the radiation from the earth of heat into space, gradually producing a shrinkage of the earth's crust, which, here and there giving way, became crumpled upon lines more or less irregular, producing partial upheavals, even though the absolute bulk of the globe was diminished by cooling."* Sir Charles Lyell mentions a fact concerning the structure of the Alleghany Mountains which seems to confirm this opinion. He tells us that the parallel ranges of those mountains consist of "strata folded into a succession of convex and concave flexures." †

But though we accept this theory with respect to mountains properly so called, we shall find that it does not always apply to hills. In most cases these have been formed by denudation, a process which is continually at work, and to which we may attribute almost all

* *Physical Geography and Geology of Great Britain*, p. 43.
† *Elements of Geology*, p. 495.

the picturesque features which give charm to the landscape.

Denudation.—It will be evident on a little reflection that when the bed of the ocean, or any part of it, first appears as dry land, it will present none of that variety of detail which now marks the earth's surface. The material carried down by a river to the sea, or which is excavated from a rocky cliff by the action of the waves, is spread out in long stretches of mud, sand, or gravel; and when these sands and beaches become permanent dry land, they may present undulating or swelling outlines, but will be destitute of the peaks, chasms, and precipices which give grandeur to our mountains. The moment, however, that the dry land appears, it becomes exposed to a new set of forces, which carve out, as it were, the features of the country, and turn shapeless masses into magnificent mountains, pleasant hills, and fertile valleys (Fig. 3). Rains wash off the softer

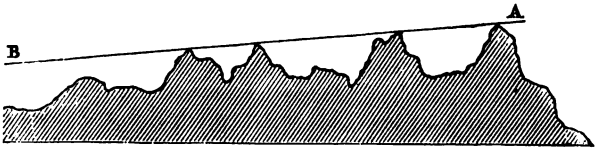


FIG. 3.—Effect of Denudation.
A.-B. shows the original surface before it was acted upon by subaerial denudation.

covering of the various eminences, and the carbonic acid contained in the water eats away the limestone and chalk. Frosts split up fragments of rock, and streams carry the *débris* to lower levels. Glaciers scoop out mountain valleys, hollow out rocky basins which afterwards form lakes, and give birth to rivers which cut out for themselves the channels in which they flow.

All the forces to which we have alluded—the action of the sea, the influence of weather, and the effect of ice and running water—are included in the term *denudation*—that is, a stripping or laying bare of the surface. But it will be seen that while the action of the sea, or marine denuda-

tion, as it is called, tends to produce uniformity, the tendency of the other agents is to produce variety, and these have played a far more important part in the physical history of our globe than is generally supposed. There is clear evidence to show that not only the Oolitic strata which now forms a bold escarpment to the west, in the Cotswold Hills, but also the chalk which lies above it, once stretched right across the valley of the Severn, up to the base of the Malvern Hills. But, partly owing to marine denudation,—principally, however, through the agency of rain and running water,—a large portion of these rocks has been removed, leaving an Oolitic escarpment in the Cotswolds and a chalk escarpment in the Chiltern Hills, the chalk, being the more easily dissolved, having been removed to a greater extent. In this way, we see, the Cotswolds and Chilterns have been formed.

Another striking example of the effect of denudation is exhibited in the *Weald* of Surrey, Sussex, and Kent. Over this area the chalk strata once stretched without interruption; but, through the combined agency of the sea, rains, and rivers, the chalk has been cleanly scooped out, the result being the formation of two bold escarpments, one facing the south and the other the north, and known respectively as the North and South Downs. In the district known as Saxon Switzerland, and in the valley of the Tweed, nearer home, we have examples of plateaus which have been so intersected by river channels as to lose their original character, and to appear now as a series of hills. The same thing is taking place in the plateau of Abyssinia, which is deeply intersected with the affluents of the Blue Nile and the Atbara; and the material thus eroded is borne down by the Nile to fertilize the valley of Egypt.

It thus appears that hills are very often formed out of plateaus, or, in some cases, form merely the edge of a plateau. At first, the hills will be more or less flat-topped and shapeless, but as the process of denudation goes on the corners are rounded off, softer strata are removed, tributary streams carve out their several channels, and the

hills become picturesque. It is evident, therefore, that the longer any surface is exposed to denudation,—in other words, the more it is weather-worn,—the greater variety will there be in detail. Hence it is that, as a rule, districts where the older rocks prevail are most celebrated for their scenery. When denudation has been continued for a very long period, the whole of the sedimentary rocks are in some cases removed, and the harder granite and other igneous rocks come to the surface. It is the contrast between their rugged outlines and the more rounded forms of the sedimentary strata to which most of the romantic beauty of mountain districts is owing.

Of all the denuding forces that have been, or are still, at work, none have been more powerful than *glacier action.* As the ice-river slowly creeps down the slope of a mountain, it carries everything before it with irresistible force. Not only soil, trees, and stones, but the softer strata of rocks are stripped off, and the harder rocks over which it passes are ground and polished as smooth as glass. A stream issuing from the end of the glacier carries away the sand and mud formed from the softer materials which it has crushed and ground to powder; and when the glacier has reached its farthest limit and melts, it deposits its burden of stones, rocks, and rubbish in what is called a terminal moraine. In many parts of the British Islands distinct traces of glacier action may be observed; and it is scarcely too much to say that all our mountain valleys have been formed by this agency. The softer material scooped out has been carried down to the valleys and helps to form the fertile soil. Professor Ramsay is of opinion that the rocky basins in which most mountain lakes lie have been excavated by glacier action. He points out that in the region of the Alps all the large lakes lie in the direct channels of the ancient glaciers; and it is certainly remarkable that in Northern Europe and in North America, where we know that in past ages glaciers were numerous, lakes are of much more frequent occurrence than in the warmer regions farther south. At any rate, in the Lake [illegible]t of Cumberland and Westmoreland, as well as among

the lakes of Killarney and in various parts of Scotland, glacier action may be distinctly traced.

At the close of the Glacial period, when, owing to a change in the climate, glaciers disappeared from many parts of Northern and Central Europe, or retreated into the recesses of the mountains, the valleys which they had previously occupied would be taken possession of in many cases by rivers. Sometimes, as may be observed in some of the Italian lakes, the terminal moraine would dam up the water and form a mountain lake; in time, however, the water would gradually cut a channel through such obstructions. Where, however, a hollow was formed in a rocky bed, the lakes would be of a more permanent character. Still, the sediment carried down by the river must in time fill up such lakes. It is well known that the river Rhone, before entering Lake Geneva, is very much discoloured; but it issues from the lake in a clear blue stream. The solid matter which has been thus filtered out of the river is gradually filling up the lake, for there is indisputable evidence to prove that it was once much larger than it now is. The same thing has taken place in our own island. In many of the "straths" of Scotland and dales of England may be traced the outlines of ancient lakes, now turned into marshes or into fertile fields.

But while a river is thus filling up depressions in one part of its channel, it is scooping out another part; for, of course, the amount of solid matter required to fill up a lake must have been transported from some other part of the river-basin, and is a measure of the amount of denudation that has been going on. If we follow the course of a river from its mouth towards its source, we shall probably find that in some part or other it flows between lofty cliffs, and in almost every case in a well-defined channel. Now, these cliffs and this channel have been formed for the most part by the river itself. A striking example is seen in the *Falls of the Niagara.* There is evidence to show that since the river began to flow in its present channel the Falls have receded a distance of seven miles. The river at first seems to have fallen over a steep escarpment, which

may be seen at Queenstown, about seven miles from Lake Ontario. This escarpment is the termination of a plateau of limestone, in which the falling water has eaten out a deep channel, in some places to a depth of 300 feet, for a distance of seven miles south-west of Queenstown, and every year the Falls are still slowly receding.

A still more striking proof of the great eroding power of running water may be seen in those rocky defiles called *cañons* which characterize the Pacific coast of North America. These cañons are generally found where a river breaks through some mountain range on its way to the ocean, and the Cascade range is remarkable in this respect. Thus we have the cañons of the Stikeen, in Alaska, the defiles of the Fraser, the gorges of the Columbia, and those of the Colorado. The great cañon of the Colorado is 300 miles in length, with perpendicular walls 5000 feet in height; yet there is undoubted evidence to prove that this and the other gorges have all been formed by streams of running water slowly wearing out channels to the Pacific. In the upper part of the Fraser there are parallel terraces on the opposite sides of the valley, and rising to a considerable height. These mark the successive elevations at which a lake formerly stood, while the river was gradually wearing down the Cascade Mountains and opening for itself an outlet to the sea. The parallel roads of Glen Roy, in the county of Inverness, are probably of a similar origin; but in that instance the outlet to the lake seems to have been blocked up by a glacier.

Deltas.—We have said that the amount of solid matter carried down by a river is a measure of the denudation which it accomplishes. The amount is far greater than we should ever imagine. It has been computed that the river Mississippi carries down to the sea 7000 million cubic feet of solid matter annually, and the quantity carried down by the Ganges is still greater. Sir Charles Lyell puts this in a very striking manner:—"If a fleet of more than eighty Indiamen, each freighted with about 1400 tons weight of mud, were to sail down the river every hour of every day and night for four months continuously, they would

only transport from the higher country to the sea a mass of solid matter equal to that borne down by the Ganges, even in this part of its course (Ghuzepoor), in the four months of the flood season."* Now, all this solid matter goes to form the delta of the Ganges. In a similar manner, though on a less scale, all the other deltas in the world have been formed; and thus the old belief of the ancient Egyptians, that Egypt was the gift of the Nile—so far, at least, as Lower Egypt is concerned—is literally true. It is impossible to say in a few words why some rivers should end with deltas while others form estuaries. There may be special reasons in some cases. Something will depend upon the quantity of solid matter carried down by the river, something on the fact whether the coast is rising or sinking. But in ordinary cases it would seem that all rivers have a tendency to form deltas. The vast estuary of the La Plata is much smaller than it once was, and is full of shallows and sandbanks.

We have thus sketched out very briefly some of the changes that are constantly taking place on the surface of the earth. The features of the landscape are slowly carved out by the various agents of denudation, and the chips and waste, as it were, in nature's workshop are borne away by the rivers, to form new strata at the bottoms of seas and lakes. It will be both interesting and useful for the student, when taking his walks in the country, to notice the effects of denudation, and to endeavour to explain them. Here he may observe a broad valley which has been scooped out by a rivulet; there he may notice the high cliffs through which the river has forced a passage. On the sea-shore he may meet with isolated and perforated rocks, worn into fantastic shapes by the restless waves. Occasionally he may trace the outline of an ancient lake, which has either been drained by its waters bursting through some barrier, or which has been silted up by the detritus brought down by the stream which fed it. Sometimes he may meet with a huge rock of curious shape, standing out boldly on a hillside, or springing out like a

* *Principles of Geology*, vol. i. p. 481.

wall from the face of a cliff; and upon close examination he will find that it is of some harder rock than usual—most probably of igneous origin—which has resisted the effects of the weather, while the softer strata around it have been worn away. Such "dykes" are very common in Arran, Bute, and the adjacent islets, and seem to represent the ancient lava streams of a volcanic system.

We have thus endeavoured, in the preceding chapters, to explain the nature and present condition of the earth's crust. If we accept the theory that the earth once existed in an incandescent state, then there must have been a time when it was a gaseous ball. As the temperature became slowly reduced by radiation the metallic elements would pass first into a liquid and then into a solid form, and oxygen and hydrogen would combine to form aqueous vapour. No sooner would these metals have become solid than they would come under the influence of oxygen, and oxides and salts would be formed, thus providing material for the solid rocks. Vast quantities of oxygen and other gases would become locked up, as it were, in combination with the materials of the earth's crust, and in the aqueous vapour that had been formed, the residuum being left as an atmosphere surrounding our planet.*

We have supposed the earth to have reached a stage when it was more or less solid at the surface; for some considerable time after this the temperature would be too high to permit the existence of water, but gradually the steam which filled the air would be condensed, and the water would collect in the hollows on the earth's surface. The dry land would now be exposed to all those forces which we have included under the term *denudation*, and the material for sedimentary rocks would be deposited in lakes and seas. These rocks would in time become dry land, and would then themselves become exposed to weathering; and thus a series of constant changes has been going on through the lapse of ages, which has resulted in the world we live in.

* Lockyer.

CHAPTER VI.

The Atmosphere—Wind and Storms.

The Atmosphere.—The air, or atmosphere, completely envelops the earth to the height of fifty or a hundred miles. As it is subject to the law of gravitation, and is also a highly elastic fluid, the lower strata are pressed down by those above, and become denser. It follows, also, that the atmosphere exerts a certain pressure at the earth's surface, and this is found by experiment to be, upon the average, 14·7 lbs. to a square inch. This pressure is equal in weight to a column of mercury a square inch in section and 29·9 inches in height, the temperature being 60° Fahr. It is upon this fact that the principle of the barometer is founded.

Under ordinary circumstances the pressure of the atmosphere exactly balances the column of mercury at the height just mentioned. If, from any cause, the pressure should be increased, the mercury will rise; if the pressure be diminished, the mercury will fall. Lines connecting places where the pressure is the same are termed *isobars*. When we ascend a mountain we find that the air becomes more and more rarefied the higher we climb. This is indicated by the mercury in the barometer, which falls as the pressure diminishes; hence it is possible, by means of a barometer, to approximate to the height of a mountain. Another way of measuring altitudes is by noticing at what temperature water will boil. At the surface of the earth water boils at 212° Fahr., but at the summit of a mountain it will boil at a lower temperature, owing to diminished pressure. On the other hand, it would require a higher temperature than 212° Fahr. to bring water to the boiling point at the bottom of a deep mine. It is thus seen that heights

may be measured by means either of a barometer or thermometer; but in both cases the principle is the same, which is, that the density, and therefore the pressure, of the atmosphere diminishes as we ascend from the surface of the earth. It has been found by experiment that at an elevation of 18,000 feet the pressure is only 7·5 lbs., and therefore the mercury would stand at 15 inches. At a further elevation of the same amount the pressure would be again halved, so that, if it goes on decreasing at this ratio, at the height of forty or fifty miles the air would scarcely exhibit any pressure at all; still it may exist, though in a state of extreme tenuity, for a considerable distance beyond that limit.

The atmosphere is chiefly composed of two gases—nitrogen and oxygen, the latter playing the more important part in the economy of nature, as it is necessary for combustion, and its consumption in the tissues is the source of animal heat. Out of 100 parts of the atmosphere there are, in volume, 77·95 parts of nitrogen, 20·61 of oxygen, 1·40 of water, and ·04 of carbonic acid gas. All gases possess the property of readily mixing with each other without regard to their specific gravities. Thus, carbonic acid gas, arising from the decay of vegetable matter or from the craters of extinct volcanoes, although half as heavy again as atmospheric air, readily diffuses itself into the higher regions of the atmosphere. Were it not for this peculiar property of gases—acting according to what is termed the *law of diffusion*—poisonous exhalations rising from the earth in various parts would accumulate near the surface, and render the atmosphere unfit for animal life.

The atmosphere is the medium for distributing the light and heat which we derive from the sun, and upon its agency depends every variety of sound. It is also the great storehouse of clouds and hail, snow and vapour.

Light, as we have already explained, is caused by a rapid vibration in the particles of a luminous body. This vibration is communicated to the luminiferous ether, and transmitted in a series of waves to the optic nerve. A

luminous ray is the line in which such undulations are propagated. When a ray of light strikes upon a body, part of it passes through, part is reflected, and part is absorbed. This is the case upon whatever kind of substance the ray may happen to fall. For though we call those bodies transparent through which light passes easily, yet a small portion passes even through opaque bodies; and, on the other hand, in transparent bodies all the light is not transmitted; a part is reflected, otherwise the objects would be invisible. The atmosphere, when dry, is very transparent both to light and heat; hence the air, if pure, would neither be illuminated nor heated by the sun's rays. It always contains, however, a certain quantity of aqueous vapour, as well as a quantity of fine dust, which we may see as motes in a sunbeam, and these minute particles have the power of reflecting and diffusing the solar rays.

When a ray of light passes obliquely from one medium into another of different density, it is bent from its course, and this change in direction is called *refraction*. As, therefore, the atmosphere is a medium of greater density than luminiferous ether, and as the different strata of the atmosphere increase in density as we approach the surface of the earth, a ray of light coming to us from the sun or any other of the heavenly bodies undergoes refraction unless it comes from the zenith. The effect of refraction upon a ray of light passing obliquely through the atmosphere is to cause it to proceed in a curve instead of a straight line. Now, as objects always appear to be in the direction in which the rays proceeding from them enter the eye, the result is that all heavenly bodies, unless they are in the zenith, appear at a greater altitude than they really are; and this source of error is taken into account by astronomers in all their calculations. A star situated half-way between the zenith and the horizon appears too high by about 1′, or the 30th part of the moon's apparent diameter; but the amount of refraction is much greater near the horizon, in consequence of the increased density of the atmosphere, and the consequence is that we can see the sun and moon for a short time after they have actually

set below the horizon. Within the Arctic circle, where the sun is just below the horizon for weeks at a time, it has sometimes been seen several days before it has actually risen.

A ray of light passing through the atmosphere undergoes both reflection and refraction. As it advances into media more and more dense the refraction is increased, while the reflection and dispersion are assisted by the fine dust and aqueous vapour which the air contains. It is to this constant reflection from minute particles in the air and from material objects on the earth's surface that we owe the broad light of day. Were there no atmosphere, there would be no light, except in a line with the sun's rays and the light reflected from material objects. Outside the direct influence of these rays all would be wrapped in total darkness. It is said that out of 10,000 rays of light which enter the atmosphere 8000 reach the earth if they fall perpendicularly through clear air; the rest are absorbed. If the angle at which the light enters the atmosphere be 50°, the number of rays which reach the earth is about 7000; if 7°, it is less than 3000. This explains why the sun is so much hotter when in a vertical position, and the little effect it has when just on the horizon.

Twilight is mainly the result of reflection. When the sun is a little below the horizon, just before sunrise or a little after sunset, its rays, shooting into the upper regions of the atmosphere, are partially reflected towards the earth, and afford a faint daylight. Within the tropics twilight continues until the sun is 16° below the horizon; and as the sun's path in the tropics is almost vertical, the period of twilight is very short. In middle latitudes the limit is 18°, and in the Polar regions 20°; and as the sun's descent in high latitudes is very oblique, there is always a long twilight in Polar regions. For the same reason twilight is longer in winter than in summer.

Heat.—The atmosphere receives very little heat from the direct rays of the sun in their passage through it to the earth; it is chiefly heated by contact with the earth, and then by conduction and convection the heat is transmitted

upwards. When the heat rays reach the earth's surface they are checked, and warm the land and sea. The air immediately in contact with the surface partakes of this warmth and communicates it to the strata above. Hence we find that the higher we ascend into the air the colder it becomes: for the warmth comes from below. There is also another reason: the lower strata are denser than those above, and hence contain more heat. Expansion of the air always produces cold; increase in density is always accompanied by increase of temperature. The tops of mountains also radiate heat much quicker than the general surface of the ground, hence another cause of diminished temperature as we increase our altitude. It is sometimes said that an elevation of 300 feet makes a difference of 1° Fahr. From the observations taken during balloon ascents, however, it would appear that up to a certain elevation the decrease in temperature is much more rapid than this, but that afterwards it goes on more slowly.

Sound.—The atmosphere is the medium of sound; without it there would be everywhere a death-like silence. Sound, like heat and light, is the result of vibrations, but the undulations are propagated, not by the luminiferous ether, but by the air itself, or some other elastic medium; they also differ in direction from those which produce heat and light. The vibrations of a sonorous body throw the particles of the air into a backward and forward motion. This may be illustrated by a number of ivory balls placed in a row at short distances apart. If the first receive an impulse which drives it against the second, each ball will strike the one in front and be brought to rest; the impulse is carried on through the whole length of the row, but the balls—with the exception of the last—only move forward and backward. The vibrations in the luminiferous ether have an upward and downward motion, like waves of water; the vibrations in the atmosphere which produce sound have, as we have seen, not an upward and downward motion, but a motion forward and backward.

The *pitch* of a note depends solely on frequency of vibrations—the quicker the vibration the higher the pitch.

The *intensity* of the sound, the pitch being the same, depends upon the energy of the aerial vibrations, and therefore upon distance, the density of the atmosphere at the place where the sound is generated, and the direction of the wind. It is also increased by the proximity of a sonorous body. The *velocity* of sound increases with increased temperature. At the freezing point the velocity may be taken as 1090 feet per second, and the increase is nearly two feet for every degree of the centigrade thermometer.

Winds.—Heat expands the air and makes it lighter; cold condenses the air and makes it heavier. Now, it is the tendency of all fluids to preserve a state of equilibrium, and one of the chief conditions of the equilibrium of the atmosphere is that every stratum should be of the same density. If, therefore, the air in any particular locality become rarefied, the denser air in the vicinity will flow in to restore equilibrium, and a wind is produced. This may be illustrated by the phenomena of the *land* and *sea breezes* which are experienced with more or less regularity all over the world. Land is heated more rapidly than water, but cools more quickly. During the daytime, therefore, the surface of the land is warmer than the sea, and the atmosphere which is above the land partakes of its higher temperature. The colder air from the sea rushes in to the land, and a sea breeze is felt. After sunset the land radiates its heat more rapidly than the sea; the atmosphere over the land, therefore, becomes chilled and denser than that over the sea, and a land breeze begins to blow, and continues until both atmospheres become of the same density.

The *trade-winds*, which prevail within the tropics, may be explained in a similar manner. The tropical parts of the earth being hottest, the atmosphere there is more rarefied than in other regions, and there is a strong ascending current, the air seeking a stratum of its own density. The colder air from the poles flows in to restore equilibrium, and two *polar currents* are thus produced. Were the earth at rest, these currents would blow directly from

north to south; but the rotation of the earth upon its axis causes them to partake of an easterly direction. The earth, in revolving from west to east, carries the atmosphere along with it. A particle of air, therefore, at the equator moves with the earth at the rate of nearly 1000 miles an hour, while a particle near the poles has little or no movement eastward. A current of air, therefore, which comes from the poles towards the tropics, moves more slowly than the parts of the earth over which it is passing. It is therefore left behind, and appears to move in the opposite direction—that is, from east to west. Thus, instead of coming directly from either pole, the winds blow from the north-east and south-east respectively, and the nearer they approach the tropics the more easterly they become, until at length their course is almost due east and west, and they are known as the trade-winds.

The polar winds necessitate *return currents*, otherwise there would be a vacuum at the poles. These return winds are supplied by the ascending current which is constantly rising within the tropics. At first these winds are upper currents, but as they recede from the equator they become chilled, and therefore denser, and gradually descend, and just outside the tropics they begin to be felt as surface currents. These winds are also affected by the earth's rotation; for, starting with a rapid motion from west to east, they pass over regions where the motion to the east is less and less rapid, and thus the excess of their easterly movement is felt, and instead of blowing directly from the equator to the poles, they are felt as south-west and north-west winds respectively, according as they blow over the northern or the southern hemisphere.

Calm-belts.—There is thus a complete circulation of the air from the poles to the equator and back again to the poles; and this circulation, as we shall find, has an important bearing upon the climate of the globe by transferring the warmth of the tropics to colder regions, and the moisture of the southern ocean to the continents of the north. Wherever these currents meet or cross each other, there we find a belt of calms. Such a belt is at the

meeting of the north-east and south-east trades. It is four or five degrees in breadth, and is known to sailors as the *Doldrums*. Here the winds seem to neutralize each other, and it is said that sometimes, far out at sea, a candle will burn without flickering. This *Zone of Calms*, however, is subject to heavy rains and violent thunderstorms, owing, probably, to the meeting of two atmospheric currents of different temperatures and containing different amounts of aqueous vapour. It is sometimes called the zone of variable winds, because the calm is often broken by light breezes from various parts. This equatorial belt does not coincide with the equator, but lies about 5° north of it. This is owing to the preponderance of land in the northern hemisphere. Owing to this preponderance, the thermal equator, or line of greatest heat, lies to the north of the geographical equator; and as the ascending current will always be strongest at the line of greatest heat, the trade-winds naturally range themselves on each side of the thermal equator.

Besides the Doldrums, there are two other calm-belts known respectively as the *Calms* of *Cancer* and *Capricorn*. We have said that within the tropics the return winds are upper currents. They descend and cross the polar winds at these zones, and beyond them prevail as surface winds. It is supposed by some that the trade-winds cross each other at the Doldrums—in other words, that the south-east trade supplies the return wind in the northern hemisphere, and the north-east trade the return wind of the southern hemisphere. Some geographers doubt this, but there are strong reasons in favour of the supposition. We have mentioned that the equatorial belt of calms lies north of the equator, coinciding with the line of greatest heat. Now, as the sun moves northward and southward within the tropics, this line of heat will not be stationary, but will follow the sun. Hence, from May to December the Doldrums moves northward, and southward from December to May. The northern limit is about ten degrees from the equator; the southern limit almost touches the equator. Of course this movement affects the other calm-belts, and,

therefore, the position on the earth's surface where the return winds begin to prevail as surface currents will vary with the seasons. This fact is to be borne in mind when we come to consider the distribution of rains.

The preponderance of land in the northern hemisphere causes, we have said, the equatorial belt of calms to lie several degrees north of the equator. One consequence of this is that the region of south-east trades has a much greater breadth than that of the north-east trade-winds. Again, in the Atlantic especially, the south-east trade is much stronger and "fresher" than the north-east. This may in some degree be owing to the belt of deserts which stretches across Africa and Asia. The air over these barren tracts being exceedingly rarefied, especially in summer, a portion of the north-east trade is required to restore equilibrium, and thus the wind is checked and weakened. Another effect of the land upon the winds is that the trades are never regular, except at some distance from the shore. The unequal heating of the land and sea changes the permanent trades into periodical winds, and hence along all the coasts within the trade-wind region monsoons prevail to a greater or less extent.

Monsoons.—It is in the Indian Ocean, however, that monsoons are most perfectly developed. The word monsoon means a *season*, and it is applied to these periodical winds because they follow the seasons with great regularity. In summer, when the sun is north of the equator, the plains of Central Asia rarefy the superincumbent air. The north-east wind is therefore checked in its course, and the south-east wind, after crossing the equator, is turned into a south-west wind. This takes place from April to September. Between October and March the sun is south of the equator, and hence there is a rush of air to the south of Africa, and the north-east monsoon prevails. The continent of Australia has a similar effect upon the trades; and this is, no doubt, the main reason why the trade-winds do not blow with such regularity in the Pacific as in the Atlantic. Recent investigations prove that the south-east trades only blow permanently over that part of

the ocean which lies between the Galapagos Islands and the Marquesas. In the Indian Ocean the trade-winds blow with great constancy between 10° and 28° south, from Australia to Madagascar.

Variable Winds. — The trade-winds are permanent winds; the monsoons are periodical; outside the tropics the winds are variable. Here there is a struggle between the return trades, as they are sometimes called, and the polar currents. As a rule, however, the return trades follow the oceans, while the polar currents travel across the continents; hence we explain the mild moist climate which characterizes the west coasts of continents in temperate regions. On the seaboards of continents where these opposing winds meet there is a constant struggle for the mastery, and hence the frequent changes which characterize the winds in extratropical regions. In Great Britain the east winds prevail generally from January to May, the west winds from June to December; in Ireland the westerly winds prevail for three-quarters of the year. It has often been noticed that when there is a mild winter in Europe there is a severe season in America, and *vice versa.* The reason is, that if the south-west winds are very strong they prevail to some extent on the continent of Europe as well as in the Atlantic; if, on the other hand, the north-east wind is the more powerful, it brings frost and snow to the coast of Europe, and at the same time forces the south-west wind, with its warm showers, to keep to the western side of the Atlantic.

Recent investigations seem to show that all variable winds are more or less rotatory. If we examine a series of weather charts, we shall observe that there are two distinct systems of pressure which change their position from day to day. One system is indicated by isobars enclosing areas by low pressure, *into* which the winds all round blow vorticosely in a direction, in the northern hemisphere, contrary to the movement of the hands of a watch. The other is indicated by isobars enclosing areas of high pressure, *out* of which the winds blow on all sides, but in opposite directions to those belonging to the low pressure

spaces. The first system are termed *cyclones*, and they are always more or less of a stormy character; the latter are termed *anticyclones*. These areas of high and low pressure, with their accompanying winds, travel generally in an easterly or north-easterly direction in the northern hemisphere. What are the precise laws which regulate their origin and the direction in which they travel are at present unknown.

Storms.—Every storm which visits our coasts is cyclonic in character; but the term *cyclone* was formerly applied only to those storms of a destructive character which have their origin in the tropics. The three great centres for these storms are the West Indies, the China Sea, and the Indian Ocean. Like the ordinary cyclonic storms which visit our coasts, these tropical storms have a two-fold motion; they revolve round a central axis, and at the same time have an onward motion in a given path. North of the equator the storms revolve from east to north, and then by west to south, or in a direction contrary to that of the hands of a watch; but in the Indian Ocean, south of the equator, the cyclones revolve in an opposite direction. The course of the storm is also different in the two hemispheres. In the West Indies the path of the storm runs from the south-east to the north-west, and then curves round to the north-east; in the Indian Ocean it begins at the north-east, and then curves round to the south-east.

In the West Indies these cyclones, or hurricanes, as they are there generally termed, occur most frequently from July to October. They generally commence near the northern coast of South America, and follow the chain of the West India Islands; then, turning to the north-east, they keep to the track of the Gulf Stream, and generally die out about the latitude of New York. The length of the storm-path is sometimes 3000 miles, along which the storm travels at the rate of 30 or 40 miles an hour. At the same time it is revolving at a tremendous speed, the wind blowing at the rate of 100 miles an hour, and sometimes even with greater velocity. In the China Sea, where the storms are termed *tyfoons*, they also prevail

from July to October—most frequently, however, in July, August, and September. In the Indian Ocean the storm-path sometimes extends from the neighbourhood of Java in a south-westerly direction towards Madagascar, and then turns to the south-east. The cyclones of the Indian Ocean prevail from January to April.

The breadth of the storm, of course, varies; but in some instances it has amounted to 600, and even 1000 miles. Owing to friction, the axis of the storm is not perpendicular, but bends a little forward, and the revolving motion, therefore, is not quite horizontal. This causes continual intermixture of the lower and warmer strata of air with those that are higher and colder; and thus torrents of rain, and sometimes violent electrical explosions, are produced. In consequence of the rotation of the air, the wind blows in contrary directions on opposite sides of the storm; and the violence of the blast increases from the circumference towards the centre. At the centre, however, there is a dead calm over a space varying from five to thirty miles, according to the size of the storm. Hence, when a cyclone passes over any locality, the wind at first blows moderately, but gradually increases in violence. Then in a moment, when the storm is raging its fiercest, there is a sudden lull, which lasts for a certain interval. The storm is then renewed with all its former strength, but the wind blows from an opposite quarter. Gradually, however, it decreases in violence as the outer edge of the storm is approached.

In consequence of centrifugal force, the air is rarefied both in the centre of the storm itself and also for a considerable distance outside of it. Hence a sudden fall of the barometer is a sure indication of the approach of a cyclone. The captain of a ship is in this way sometimes warned of his proximity to a storm; and knowing the direction in which it travels, he may often, by changing his course, avoid it. Owing to the diminished pressure in the vortex of the storm, and also to a less extent over the whole area covered by the cyclone, the water rises above its usual level; and the mass being driven bodily forward

by the tempest, when it reaches land it rolls in like a huge wave, causing immense destruction.

We have dealt thus fully with the tropical cyclones because it is very probable that the local storms which visit our coasts are precisely of the same character, and only differ from them in degree. In both cases the storms are doubtless caused by the meeting of currents of air coming in opposite, or nearly opposite, directions. It will be noticed that in the Indian and Pacific Oceans the period of their recurrence coincides with the changes in the monsoons. The storms of the Atlantic may probably have some connexion with the Gulf Stream; and our local cyclones are doubtless caused by the struggle between the polar winds and the return trades.

We have already stated (p. 78) that all variable winds are probably rotatory in character, and that there seem to be two systems of pressure, which change their position from day to day, and thus produce changes in the state of the weather. Now if, as we have suggested, these two systems of pressure are caused by the struggle between the polar and the south-west winds, it is probable that when the north-east wind prevails an anticyclone is the result. For the cold, dry air of the polar current must be denser than the warm, moist atmosphere of the return trade; and, besides, it is natural, if the north-east wind is the stronger, that the wind should shift round from north to east and then to south, instead of in the contrary direction. Such a change is accompanied by fine, settled weather. Should, however, the south-west wind prevail, a system of low pressure is the result, the winds shift round from south to east and then to north, and the weather is broken and unsettled. This would also explain how it is that the gales which visit our shores always come from the south-west; and as their direction and rate of motion are noted on the other side of the Atlantic, their arrival in England can be anticipated by the telegraphic cable.

CHAPTER VII.

Rain and Snow.

Vapour rises from every portion of the surface of the earth at all times and in all temperatures, even from snow. This evaporation is greatly increased by the heat of the sun, and hence is carried on to a greater extent within the tropics than in extratropical regions. The atmosphere, however, in those parts has a greater capacity for holding moisture in an invisible form than in places where the temperature is less. When aqueous vapour rises from the earth it is generally invisible, but as it ascends into higher strata it is condensed by cold, and becomes visible in the form of clouds.

Clouds may be grouped into three classes: the cirrus, cumulus, and stratus. The *cirri* are those light fleecy clouds which float high up in the air. They have an elevation of at least three miles, and are sometimes double or thrice that height. They cannot, therefore, be composed of vapour, but must consist of minute crystals of snow or ice. It has been suggested that they are the heads of columns of vapour rising up from the earth, which become visible by condensation. The cirrus clouds for the most part arrange themselves in parallel bands, which, by the effect of perspective, appear to converge in opposite points of the horizon. In the middle and higher latitudes of the northern hemisphere their direction is from south-west to north-east; within the tropics their direction is from south to north. They would thus seem to be connected in some way with the return trades.

Cumuli are those solid snowy masses which appear so frequently in summer, and which often assume the most fantastic shapes. They generally appear soon after sun-

rise, and, as the day advances, ascend higher, sometimes disappearing altogether towards evening. Not unfrequently, however, they become more numerous towards the close of the day, and assume a darker tint presaging rain. The *stratus* is a horizontal band of cloud, which forms at sunset and vanishes at sunrise. Besides these three primary classes of clouds, there are several compound forms, such as the *cirro-stratus*, *cumulo-stratus*, and *cirro-cumulus*. The last-mentioned forms what is called a "mackerel sky," which is said to portend wind. In addition to these varieties we may mention the *nimbus* or dark rain-cloud.

Mountains have a great influence on the formation of clouds, for they not only force the currents of air to rise into higher and therefore colder strata, but their cold summits also assist in the process of condensation. Hence it is that mountains, even when not of great elevation, are almost constantly capped with clouds. Sometimes a cloud seems attached to the summit of a mountain, and there remains, although a violent wind may be blowing at the time. In such cases the cloud is not in reality stationary; it is constantly being dissolved and reformed. Indeed, it is probable that, however motionless clouds may appear, they are never still. They are constantly either forming or dissolving, and this fact may perhaps explain their apparent buoyancy. When a cloud is connected with an ascending column of vapour, it increases in size; when the ascending current ceases, the particles which form the cloud begin to descend, owing to their weight, and the cloud diminishes in bulk and density. Clouds also sometimes appear to be stationary when they are in rapid horizontal motion. The cirrus clouds travel in the direction of their length, and their motion is not observed.

When clouds are high up towards the zenith they are generally white, because the particles of which they are composed reflect the light of the sun. The more they are condensed, however, the darker they become, until in the nimbus the colour is almost black. Towards the horizon clouds partake of a variety of tints, generally, however, more or

less of an orange colour. As red is the least refrangible of the primary colours, this is the hue of the last rays of the setting sun. Next to red comes orange; and hence the beautiful golden tints which adorn sunrise and sunset. Sometimes the blending of these colours with the clear blue of the sky produces a beautiful vivid green.

Fogs are of the same nature as clouds, the only difference being that they are nearer the earth. In countries like England, where the soil is warm and well drained and the air damp and cold, fogs are frequent. The presence of the warm Gulf Stream off the Banks of Newfoundland causes those frequent fogs which are met with in that part of the Atlantic. As water during the night-time is warmer than the adjacent land, fogs are very often noticed to follow a river. They are very frequent, too, in large towns, partly because such towns are often built on the banks of rivers, and partly because the artificial heat inseparable from a large town supplies some of the conditions favourable to the production of fogs. One of these conditions is that the surface must be warmer than the air; another is that the air should be calm. The proverbial London fog owes its density to particles of smoke and other carbonaceous matter being mingled with the partially condensed aqueous vapour.

Dew.—When fogs are formed, the surface is warmer than the air, but the case is exactly reversed when dew is deposited; the earth is then colder than the air in contact with it. During the day the surface of the earth is heated by the sun; the atmosphere partakes of this warmth, and is able to hold a considerable quantity of vapour in an invisible form. After sunset the earth cools rapidly, and condenses the air with which it is immediately in contact. The air thus chilled has no longer the same capacity for containing moisture which it had before, and deposits a portion of it in the form of dew. In hot countries, where the quantity of aqueous vapour contained in the atmosphere is very great, the amount of dew is very copious, and is of immense service during the long droughts, and, in some places, makes up for the total absence of rain. Dew is not

deposited on all substances alike; it wets them in proportion to their powers of radiation—in other words, according to the rapidity with which they cool. Leaves of plants, blades of grass, and wood are good radiators, while stones and metals are not. Hence in a garden the grass is very often wet with dew while the gravel walks are quite dry. More dew falls in summer than in winter, and on a clear night than when it is cloudy. In summer there is more moisture in the atmosphere than in winter, though its presence is not felt, owing to the capacity of the warm air to contain it. Anything that checks radiation lessens the quantity of dew, for the amount deposited depends upon the rapidity with which the earth and the bodies upon its surface can chill the air, and thus condense the moisture which it contains. In cloudy nights the heat radiated from the earth is reflected back, and hence the earth does not cool so rapidly as it otherwise would. Windy weather, again, is unfavourable to the formation of dew, for as rapidly as the air is cooled it is carried away without being reduced to the dew point. When the cold is so intense as to freeze the dew, *hoar-frost* is produced. This may occur on clear calm nights, when the temperature of the air is comparatively high, if the radiation be very rapid.

Rain.—The formation of rain is analogous to the deposition of dew, but is not identical with it. In both cases the moisture contained in the atmosphere becomes visible through condensation; but while dew is formed at the surface of the earth, and only deposited upon objects which themselves act as condensers, rain is formed high up in the atmosphere, and falls in showers upon all substances alike. In ordinary cases the vapour which is formed into rain first assumes the form of clouds, but this is not in all cases necessary; the exceptions are, however, very rare. When two currents of air of different temperatures meet, rain is almost certain to be produced; the warmer current is chilled, its capacity for moisture lessened, and the excess of vapour is condensed into raindrops. Occasionally, however, a cold current laden with clouds may meet a warmer

current containing comparatively little moisture. In this case the clouds are dissipated. The formation of rain seems in all cases to involve electrical disturbances.

Within the tropics, where all the phenomena connected with climate and weather take place with much greater regularity than in higher latitudes, there are two rainy seasons in the year. When the sun approaches the zenith of any place in this region, the ascending current of air becomes very strong, and carries large quantities of vapour up with it. As this current passes into colder strata, part of the moisture held in solution is condensed, and falls in heavy rains. And as the sun is twice over the zenith of every place within the tropics in the course of a year, it follows that there are two rainy seasons, though, as might be expected, the first is the more important of the two, since it discharges the moisture which has been collected during the long seasons of drought. In monsoon districts the rainy season is regulated by these winds. Thus the eastern and western coasts of Hindostan have rain at opposite seasons of the year. The north-east monsoon, sweeping over a large extent of land, is a comparatively dry wind; the south-west monsoon brings copious showers to the Malabar coast, and clothes the Western Ghauts with verdure and forests.

Countries beyond the tropics depend generally upon the return winds for their moisture; and as these winds traverse the oceans, we have an explanation of the fact that the west coasts of continents in temperate regions are generally well watered. Subtropical regions are, as a rule, deficient in moisture. They are beyond the influence of the trades, and the return winds have scarcely begun to be felt. Thus it is that we explain the scanty rains of Australia and Cape Colony. On the other hand, the equatorial belt of calms is a zone of almost constant precipitation. There, where the trade-winds meet, the ascending currents of air are constantly carrying large quantities of vapour into the colder strata of the atmosphere, part of which is immediately condensed. The greater part, however, is carried by the return trades to fertilize the temperate and polar

regions. The showers of rain are so copious in the zone of calms that fresh water has sometimes been collected from the surface of the sea.

The return winds, upon which extratropical regions mainly depend for their rains, become surface winds at the calm-belts of Cancer and Capricorn. It was mentioned in the last chapter that these belts are not stationary, but move northward from May to October, and southward from November to April. Of course, a great part of the moisture which the winds bring with them is deposited where they first strike the surface; and as, owing to the movement of the calm-belts, they strike the surface at different places in different seasons, we see one reason why, in extratropical regions, different localities have rain at different parts of the year. Thus, on the shores of the Mediterranean autumn and winter rains prevail; while in Central Europe summer rains are most general. South Africa and Australia also have winter rains.

As a rule, rain is much more abundant in the tropics than in temperate regions, since evaporation is there carried on with much greater energy. Upon the average, 97 inches of rain fall annually within the tropics; while in temperate regions the average is about 35 inches. Owing, however, to local causes, the quantity of rain that falls in some places far exceeds these figures. At Cherra Poongee, among the Khasia Mountains, in Assam, nearly 600 inches of rain have been collected in a single year. At Mahabaleshwar, in the Western Ghauts, 300 inches have been collected. Even in temperate regions the annual rainfall is often considerable. At Seathwaite, in the heart of the Cumberland Mountains, 182 inches were collected in 1862. With respect both to tropical and temperate regions, the New World is much more humid than the Old World, though in no part of America, so far as is known, does the rainfall exceed 300 inches.

Rainless Districts.—The arid nature of the Sahara, the plateaus of Arabia and Iran, and the Shamo of Central Asia, results partly from their situation and partly from the nature of the soil. They are for the most part shut in

by mountains from the rain-winds, and the heat reflected from the sand with which they are covered for the most part dissipates any chance clouds which may be brought by other currents. Wherever there are any elevations in the Sahara sufficient to condense the moisture brought from the Mediterranean—as in the plateau of Asben, for example—there we meet with abundant showers. Arabia and Iran naturally depend for their moisture upon the monsoons; but the south-west monsoon only touches the coast, while the winds from the north-east are drained of every drop of their moisture in crossing the plateau of Pamir and the Hindoo Koosh. The Shamo, again, is shut out from the rain-wind of the south-west by the Himalayas and Kuen-lun Mountains. On the west coast of South America there is a remarkable rainless district, the southern portion of which is called the Desert of Atacama. The absence of rain is attributed to the altitude of the mountains which bound this region on the east. The trade-winds are deprived of all their moisture in crossing the Andes, and the vapour which arises from the Pacific is carried westward by the prevailing winds. Farther south the return winds prevail, and the coast district is well watered.

Though the average quantity of rain which falls within the tropics is almost three times that of temperate regions, there are fewer rainy days. This can readily be understood when we remember that within the tropics the winds are regular, being either permanent or periodical, but outside the tropics there is a constant struggle between the north-east and south-west currents, and the winds shift round two or three times in a day. Hence currents of air of different temperatures are brought into contact, and rain is the result. It should also be remembered that a day of uninterrupted rain within the tropics is rare. When, however, it does rain in those regions the fall is enormous. In the Khasia Mountains, to which we have already referred, 30 inches of rain—an amount equal to the total average quantity which falls in England in the course of a year—has fallen in four hours.

Snow.—When the temperature of the air is near the

freezing point or below it, snow falls instead of rain. Snow-flakes consist of a collection of minute crystals, arranged in the most beautiful forms, but always hexagonal in shape. From a central nucleus six rays spring off with perfect regularity; from each of these stems smaller rays are thrown off, always at the same angle, and so again others proceed from these in the same way. There is never any deviation from the hexagonal type, though there is an infinite variety in the forms of these beautiful snow-stars. No less than one thousand different kinds have been noticed. The whiteness of snow is owing to the reflection of the light from the minute faces of the tiny crystals. Flakes of snow are about nine times more expanded than water, and hence they descend slowly, and sometimes cover the ground to a great depth. Snow is a bad conductor of heat. A cover of snow, therefore, checks the radiation of the earth, and protects the roots of plants from the frost.

As it becomes colder the higher we ascend into the atmosphere, the tops of very high mountains are covered with perpetual snow, even within the tropics. The lowest point on a mountain at which snow is never entirely melted is called the *snow-line*, or line of perennial congealation. The elevation of the snow-line varies, of course, with the annual temperature. Within the tropics, speaking generally, all mountains which rise above 16,000 feet have their summits capped with snow. As we leave the tropics the snow-line descends. On Mont Blanc it is 8500 feet, so that nearly one-half of that mountain is covered with snow. No summit in the British Islands reaches the line of perpetual snow, although Ben Nevis exceeds 4400 feet. At the island of Mageroe, on the north coast of Norway, the snow-line descends to 2000 feet, and within the Arctic circle it reaches the level of the sea.

Snow never falls within the tropics except on the tops of mountains. In the southern hemisphere there is seldom snow at the sea-level nearer the equator than the 48th parallel, and the line marking the *snow limit* passes through Buenos Ayres, Cape Town, Melbourne, and Sydney. In the northern hemisphere snow falls at much lower latitudes,

and its limit is a curved line which touches the tropics in Mexico; then, crossing the Atlantic, it passes through the north of Africa and the Mediterranean Sea. It then proceeds through Asia Minor, the southern part of the Caspian and the northern part of Hindostan, and again reaches the tropics at Canton.

Hail consists generally of a nucleus of snow coated with ice. It appears to be formed in the high cold regions of the atmosphere by the sudden condensation of vapour, and seems to have some connexion with electricity, since its fall is generally accompanied with thunder and lightning. Hail falls most commonly at the hottest time of the day, and rarely in the night; it is also common during the summer months. It is very rare in tropical countries, the reason probably being that the hail is melted in its passage through the lower strata of warm air. Hailstones as large as the egg of a hen, or even of a goose, have sometimes fallen. During a thunder-storm near the Cape of Good Hope in 1860 there was a shower of ice, some of the fragments being almost as large as a brick, and one the size of a millstone is said to have fallen at Seringapatam. These large blocks were probably clusters of hailstones which had become united together in their passage through the atmosphere.

Ice is crystallized water, and in the process of crystallization the molecules arrange themselves in hexagonal stars, just as in the formation of snow. Water in the act of freezing expands; hence the accidents which frequently happen to water-pipes during frosty weather. This expansion of freezing water, however, is an important provision in nature, for, owing to this, ice is lighter than water, and floats on its surface; and being itself a bad conductor of heat, a coat of ice once formed checks radiation from below, and thus tends to keep the rest of the water unfrozen. Ice is, however, sometimes, though rarely, formed at the bottom of a river: it is then called *ground-ice.*

When the surface of a stream is reduced in temperature, its density is increased, the cooler portion sinks, and the warmer water rises from below. This circulation continues

until the whole mass is reduced to the temperature of 39° Fahr., after which, if the temperature is still further reduced, the water begins to expand, and the cooled portion now remains on the surface until it is frozen. How, then, can ground-ice be formed? It has been suggested that the mechanical action of a running stream mixes the entire body of water together, and that it is all cooled alike. When, therefore, the whole is reduced to the freezing point, ice begins to form at the bottom of the river, for two reasons: first, because there is less motion there; and secondly, because the water is in contact with solid rock or stones, which have a cool surface. It has been noticed in Russia that ground-ice forms most readily when the sky is cloudless, and when, therefore, radiation from the bed of the river goes on most rapidly. When such ice breaks up, stones and gravel are often torn away from the bottom of the river. Pieces of rock eight pounds in weight have by this means been raised from the bed of the river Thames.

Ice is always pure, as in the process of freezing it takes up none of the substances contained in the water from which it has been formed; the ice of salt water, therefore, contains no salt. Fresh water freezes at 32° Fahr.; salt water requires a much lower temperature, so that the sea is seldom frozen except in high latitudes. The water of the Arctic Ocean is always near the freezing point, and hence in winter large fields of ice are formed. As summer approaches these frozen fields are broken up into masses of what is called *pack-ice*. Floating fields of ice, twenty or thirty miles in diameter, are very frequent, the thickness of the ice varying from ten to forty feet. These drifting ice-fields are known as *ice-floes*.

Glaciers.—The snow which covers the summits of our loftiest mountains is kept from accumulating partly by evaporation, but chiefly by means of avalanches and glaciers. When a large quantity of snow has accumulated on the top of a mountain, the lower portions are consolidated by pressure into a kind of ice; and if this takes place at the head of a ravine, the weight of the snow forces the solid

mass to descend slowly. It does not rush down like an avalanche, for the whole mass moves together, is squeezed by the sides of the ravine, and impeded by the roughness of the ground over which it moves. Creeping down slowly in this manner, it at length passes the snow-line, where in summer time ordinary snow would be melted, but upon such a huge compact mass the sun has at first little power. The surface is melted during the day, but freezes again at night. But as the glacier descends the mountain side the sun increases in power, until at length a spot is reached where the ice is melted as rapidly as it can be supplied from above: here, then, it stops, and a stream of water issuing from its extremity gives birth to some important river. A glacier seldom moves more than an inch or two in a day, and the most rapid progress never exceeds two feet daily. It moves, of course, more quickly in summer than in winter.

As the ice-stream moves down the valley it grinds

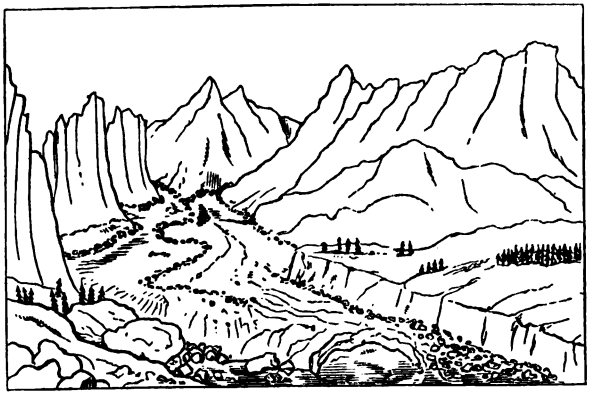


FIG. 4.—Sketch of a Glacier, showing the lateral, medial, and terminal moraines.

smooth the rocks which form the bottom and sides of its channel. Fragments of stones occasionally fall through

its cracks or crevasses, and, getting between the ice and the rocks below, are pushed along, their angles being more or less worn off, and many of them entirely ground into sand or mud. The harder fragments, becoming embedded in the glacier, furrow and scratch the rocky channel and sides of the ravine, and leave flutings and marks of *striation*, which attest the action of a glacier long after it has ceased to exist. Stones and fragments of rock also descend from the sides of the ravine upon the surface of the glacier, and form a dark line on either side, known as *lateral moraines*. Occasionally two glaciers unite, just as mountain streams do: the lateral moraines on the inside then join and form a third line, called the *medial moraine* (Fig. 4). Sometimes three or even more contribute to the main ice-river, and these feeders can always be distinguished, even after their junction, by the dark lines of *débris*. Lastly, at the termination of the glacier, when the ice is at length melted, the stones and debris brought down by the ice-stream are left in a confused heap known as the *terminal moraine*.

Occasionally a glacier seems to retreat; this takes place when, owing to an unusually hot summer, the ice is melted more rapidly than it can be supplied from above. When this happens, a portion of the ordinary bed of the glacier is laid bare, and the effect of the ice upon the rocks over which it has moved can then be plainly seen. In many parts of Switzerland smooth, round-topped rocks are met with, locally known as *roches moutonnées*, from their resemblance to the backs of sheep when lying down. These owe their round outlines and polished surfaces to the action of glaciers when they extended far beyond their present limits. And it is from noticing similar features in the landscape, as well as from observing ancient terminal moraines and the fluting and striation on the faces of rocks, that geologists have come to the conclusion that glaciers once existed in the British Islands.

The nature of glacier ice has long been a subject of controversy. The motion of the glacier is very similar to that of a river; it widens, bends, narrows, and its centre

moves more quickly than its sides. It also adapts itself to the form of the ground over which it moves, exactly as if it were a viscous substance like tar or treacle. But it differs from these substances in one important point: it cannot bear the least strain, but immediately cracks, forming deep crevasses; or, if the strain be very great, as when the glacier forms a cascade, it breaks into fragments. Professor Tyndall is of opinion that glacier ice is exactly like any other ice, and that it owes its apparent viscosity to the property of *regelation*, a principle discovered by Professor Faraday.

If two pieces of ice near the melting point are brought together, they will freeze at the point of contact. If a number of fragments of ice are placed in a basin of water and caused to touch each other, they will immediately freeze together, and a chain of such fragments may be formed. The making of a snowball is an illustration of this property of regelation. Snow consists of small particles of ice, and if pressure be applied the particles adhere, and a ball is formed. This property only belongs to ice when near the point of melting. If snow is too cold, it cannot be formed into balls; pressure only reduces it to a fine powder. Place a piece of ice in a mould and subject it to pressure; it will break into fragments: squeeze these fragments forcibly together, and the ice is once more a coherent mass, but has now taken the shape of the mould. Now apply the principle to the formation of a glacier. The snow of the *névé* is first of all changed into ice by the pressure of the superincumbent mass. Then, as the glacier proceeds on its course, the fissures and crevasses formed in one part of its progress are afterwards closed when again brought into contact by pressure from behind. The ice current may be shivered as it passes over some ledge of rock, but the parts again unite, and the glacier continues its course. When two glaciers meet, their sides at once unite firmly together and form one mass. And just as ice, when put into various moulds and subjected to a regulated pressure, can be made to alter its form, so we may understand how a glacier can be squeezed

through the gorges of the Alps, can accommodate itself to the curvatures of valleys, and can present all the features of a viscous fluid without at the same time possessing one particle of viscosity.

The length of the Swiss glaciers is sometimes between 20 and 30 miles, their width occasionally 2 or 3 miles, and their thickness from 80 to 600 feet. There are no glaciers east of Gross Glockner, except in the small group of Hallstadt. The Scandinavia peninsula presents glaciers on a grand scale, some of which descend as low as 2000 feet above sea-level. In the Himalayas they descend to about 10,000 feet, and are of large dimensions. The glaciers chiefly occur in the Karakorum range, where the Mustagh glacier is 36 miles in length. Another in the same range is said to be 60 miles long. Tasman Glacier, in the South Island of New Zealand, is 12 miles long, and almost 2 in breadth. There are many others also of considerable extent in that group of islands.

Icebergs.—We have seen that glaciers often descend several thousand feet below the snow-line; now, as the snow-line in the extreme north of Europe is only 2000 feet above the level of the sea, we can readily understand that in high latitudes the glaciers will actually reach the ocean. When this takes place, the buoyance of the water causes the end to break off, and the fragment floats away as an iceberg. The great source of icebergs in the Atlantic is Greenland, and some of them are of immense size, often several miles in circumference, and 200 or 300 feet in height. And when it is remembered that there is always seven or eight times as much ice below the surface of the water as above it, we may form some notion of their huge bulk. In the northern hemisphere icebergs are seldom met with farther south than the parallel of 48°. In the North Pacific they are not seen, as Behring Strait is too shallow to admit their passage from the Arctic Ocean; and in the Atlantic they are melted by coming into contact with the Gulf Stream. When they melt, the earth, stones, and gravel which they

carry with them are spread over the bed of the ocean, and in this way, it is supposed, the Banks of Newfoundland have been formed. In the south hemisphere the icebergs approach ten degrees nearer the equator. In 1829 one was seen off the Cape of Good Hope. It was two miles in circumference, and 150 feet high. The icebergs of the southern hemisphere are generally huge tabular masses, while those of the North Atlantic have usually spires and pinnacles.

The difference in shape between the icebergs of the Arctic and the Antarctic regions is probably due to a difference in their origin. The icebergs of the Northern Ocean are, as we have already stated, fragments of glaciers, and are of much the same density throughout. When, therefore, their bases are much water-worn, they topple over, and the bergs assume almost every variety of form. The icebergs of the Southern Ocean, on the other hand, seem to be fragments broken off from the great ice barrier that guards the South Pole, and are formed out of compressed layers of snow. Sir Wyville Thomson tells us (p. 112) that they are all distinctly stratified, that the upper layers are of snow, while the lower strata are of solid ice. It is evident that an iceberg of this structure may preserve its equilibrium for a long time, even though the base may be worn away by the water to a considerable extent. Hence they preserve for the most part their original tabular form, though occasionally masses with spires and pinnacles are met with.

CHAPTER VIII.

Springs, Rivers, and Lakes.

A portion of the water which falls upon the earth in the form of rain or snow is immediately evaporated and carried back into the atmosphere; another portion is drained off the surface in streams and rivulets, and is carried away by rivers; the remainder sinks into the ground. This portion is not lost; it circulates through the crust of the earth, in some places forming pools and underground rivers. These streams differ from those on the earth's surface, for they sometimes sink to great depths, and then again rise owing to hydraulic pressure. When water reappears again at the surface through some natural channel, it forms a spring.

Springs.—Some springs are cold, and others hot; some have their source near the surface, and others are deep-seated. Much depends upon the nature and position of the strata in which they are found. When the surface rock—using the term in its geological sense—is perfectly open and pervious to water, like sand and gravel, or even sandstone and chalk, and rests upon some impervious stratum, such as a bed of clay, the rain-water soaks through the sand or gravel, and collects in pools on the impervious stratum below. If a hole be dug through the upper stratum, water will rise to a certain height, much in the same way as sea-water filtrates into any hollow which we make in the sand at low water. But it is rarely that we find strata perfectly horizontal; generally the beds of rock slope in a particular direction. It is evident that in such cases the water which has collected on the impervious stratum will run off in the direction in which the bed slopes, and will issue as a spring at the line of junction of the two strata. Such

springs are very common on the sides of hills, and even on very gentle slopes. The supply depends directly upon the rainfall of the immediate district, and therefore they often entirely cease during a long drought.

The nature of deep-seated springs may be illustrated by the formation of an *Artesian well.* When a pervious stratum lies between two impervious strata, the water absorbed along the line of outcrop collects in pools. If now a boring be made through the surface stratum, the water will rush up to find its level. Such wells are called Artesian, from the town of Artois, in France, where they attracted attention during the Middle Ages, but they were known long before in the East. There are many such

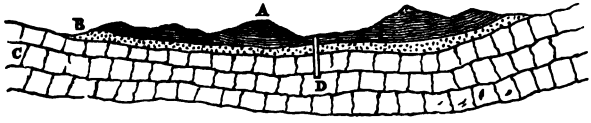


FIG. 5.—Showing the structure of an Artesian Well in London.
A, London Clay; B, Gravel; C, Chalk; D, Artesian Well.

wells in the neighbourhood of London, some of which penetrate the chalk to a considerable depth. The fountains in Trafalgar Square are fed with water from an Artesian well which reaches a depth of 390 feet beneath the surface. At Grenelle, in the suburbs of Paris, in 1834, a depth of 1600 feet was reached without finding water. When the boring-rod reached 1800 feet, water, with a temperature of 82°, rushed up in great quantities. Now, if, instead of this artificial channel, the water had found an outlet either through some fissure in the upper strata or by other natural means, it would have formed a deep-seated spring.

At Tours, in 1830, a well was sunk to a considerable depth, and when the water rushed up it brought with it a great quantity of fine sand, shells, seeds, and other vegetable matter; and judging from the nature of the shells

and the vegetable remains, it was thought that the water had come from the valleys of Auvergne, 150 miles distant. In some cases small fish with perfect eyes, unlike those generally found in underground channels, have been brought up alive. These facts suggest the idea that leaky beds of rivers are often the feeders of springs, and it is very probable that the ocean itself contributes largely to the underground circulation.

Intermittent Springs are not uncommon, and they occur under various circumstances. On the banks of the Thames, between London and Richmond, the wells regularly ebb and flow with the tide, owing to the porous nature of the river's banks. In other cases the intermission may arise from the fact that the spring issues from an opening in the side of a reservoir fed from above. If the supply be not equal to the waste, the water will sink below the opening, and the spring will stop until the reservoir be replenished. Or, if the opening happen to form a natural syphon, the discharge will continue until the cavity is empty, and then cease until the water once more reaches the highest point of the curved channel through which it issues.

Thermal, or hot springs, in many instances, derive their temperature from the depth to which the water has descended; this was the case with the water which issued from the Artesian well at Grenelle, and that experiment seemed to fix the increase of temperature at the rate of 1° Fahr. for every 60 feet of descent. In many instances, however, hot springs seem to be connected with centres of volcanic disturbance. During the earthquake at Lisbon, as we stated in a former chapter, the spring called La Source de la Reine, at Bagnères de Luchon, in the Pyrenees, was suddenly raised as much as 70°, or changed from a cold spring to one of 122° Fahr., a temperature which it has retained ever since. Indeed, it may be accepted as a general rule, that in regions where volcanic eruptions still occur hot springs are abundant, and occasionally attain a boiling temperature; while, in proportion as we recede from such centres of igneous activity, the thermal springs decrease in frequency and in average heat.

Geysers.—The most striking phenomena connected with boiling springs may be seen in the geysers of Iceland. They occur in the south-western district of the island, where nearly 100 of them are said to break out in a circuit of two miles. The Great Geyser rises out of a spacious basin at the top of a circular mound composed of siliceous incrustations, called *sinter*, deposited from the spray of the water. The basin is about 50 feet in diameter and 4 feet deep, terminating downward in a smooth pipe 8 or 10 feet in diameter. The water in the pipe appears to be in a constant state of ebullition. It rises and gradually fills both the pipe and the basin. Subterranean noises are then heard, the ground is slightly shaken, and a column of water is thrown up with low explosions to the height of 100 or 200 feet. After playing for a while like a fountain, and giving off great clouds of vapour, the pipe is emptied, and a column of steam, rushing up with amazing force, finishes the eruption. Few of the geysers play longer than five or six minutes at a time, though sometimes they last half an hour. The Great Strockr, which stands about 140 yards from the Great Geyser, is rather less in size.

The cause of these explosions appears to be the rapid formation of steam under the pressure of a high column of water. It has been found by experiment that the temperature of the water in the tube of the Great Geyser is sometimes as much as 50° above the boiling point; and this is explained by the fact that water, when long boiled, becomes more and more free from air, and thus the cohesion of its atoms is much increased. When, therefore, the heat is sufficient to overcome this force of cohesion, the production of steam is so considerable and so instantaneous as to produce an explosion. There is no doubt, also, that the water in the lower portion of the tube is kept from boiling by the pressure of the column above it, until at length the temperature is sufficiently high to overcome the pressure.

It was at one time thought that the geysers were phenomena peculiar to Iceland; but similar springs have

been met with in New Zealand; and in the upper valley of the Yellowstone, in the Rocky Mountains, there is a region which far surpasses Iceland in the number and size of its boiling fountains. The largest of these, the Grand Geyser, springs from a vast tube 20 to 25 feet in diameter, and when in a state of eruption the water rises to the height of 250 feet. The geyser district of New Zealand lies in the North Island, not far from Mount Edgcumbe. Here hot springs of mud and water abound, but the finest sight in the whole region, according to a recent writer, is the White Terrace:—"Language fails to describe the exquisite beauties of this natural wonder; it is a succession of steps, mostly of semicircular form, varying from a height of a few inches to that of as many feet. Many of these steps are hollow, and filled with water of the loveliest blue tint possible. Narrow at the top, the whole system of terraces spreads out like a fan, till at the bottom it has a circular sweep of nearly two hundred yards, while the altitude of the summit must be nearly a hundred and fifty feet. Here there is a mighty cauldron whence spouts the water that flows down the terraces, covering them with a deposit of silica. At the time of our visit the geyser was active; dense clouds of steam prevented us from seeing across the chasm, adding a weird strangeness to the scene. The theory as to the formation of the terraces is this: that formerly lava was spouted forth, forming the steps; in after times the lava gave place to water, which, holding silica in solution, covered the steps with a lovely drapery of pure white, forming fold after fold of beautiful incrustations. On one side the terraces are not so regular, but another form of beauty appears. Wherever the water flowed the fate of the vegetation was sealed; it was soon covered with a sheet of white silica, underneath which the forms of the mosses and ferns can still be seen. A marvellous formation the whole thing is, and it was with regret that we left it."

Mineral Springs.—All springs are more or less charged with mineral matter, generally in the form of *salts*. When

this saline matter is in excess the springs are called mineral. This is frequently the case with cold springs, which often contain, in an invisible form, solutions of iron, lime, salt, or other substances, but is always the case with thermal springs. For the warm water, in circulating through the crust of the earth, dissolves certain portions, and often deposits large quantities of mineral matter on the surface. The basins and mounds of geysers have been thus formed. Some springs contain silica; others, iron; and others, again, gold. Indeed, there is scarcely a substance known that has not been detected in greater or less quantities. The hot springs of Bath have a temperature of 120°, which is much above that of any other springs in England, and the minerals held in solution are sulphates of lime and soda and the chlorides of sodium and magnesium. Various gases, especially nitrogen and carbonic acid, are also evolved from these springs. The thermal springs at Buxton have a temperature of 82°.

Calcareous springs, or those containing the carbonate of lime, are very common; for water, when charged with carbonic acid, easily dissolves limestone rocks. In northern Italy calcareous springs, depositing a kind of chalk or limestone called *travertine*, are numerous. In some instances compact layers fifteen or twenty feet in thickness, which serve as excellent building-stone, have been deposited. At the baths of San Filippo, in Tuscany, a manufacture of medallions in basso-relievo is carried on. The water is caused to drop in spray upon moulds which have been rubbed lightly over with a solution of soap, and a deposition of solid matter like marble is the result, yielding a beautiful cast of the figures formed in the mould. Ferruginous or chalybeate springs are such as contain iron. The water of almost all springs contains more or less of this metal in solution, and some are so copiously impregnated with it as to stain with red the rocks and herbage over which they flow. At Eifel, on the left bank of the Rhine to the north of Coblentz, there are springs which bring nearly two tons of iron to the surface every twenty-four hours.

We have already referred to the siliceous deposits of the geysers. Silica is not easily dissolved, and if water hold any considerable quantity in solution it must have a high temperature. None, therefore, but very hot springs make siliceous deposits. There are, however, some celebrated siliceous springs at San Michael, in the Azores. Cheshire is celebrated for its brine springs. There are also some springs in Worcestershire extremely rich in salt. These brine springs rise up through strata of sandstone and red marl, which contain large beds of rock-salt. The Carlsbad waters, in Bohemia, bring to the surface annually a quantity of sulphate of soda that would yield 15,000 tons of the crystallized mineral. Arsenic is often met with in mineral waters. There is a spring near Utica, on the north coast of Africa, which contains 72 grains of saline matter per gallon, of which 12½ grains are arseniates of potash and soda. The waters, however, are said to be inoffensive, and are used for drinking both by men and cattle. Among the gases evolved from thermal springs, oxygen, hydrogen, nitrogen, and ammonia are very common, either in a free state or in combination. Nearly 90 per cent. of the gases evolved by the springs of Aix-la-Chapelle consist of nitrogen, while the springs in the volcanic district of Auvergne produce immense quantities of carbonic acid gas. Boracic acid is almost peculiar to Tuscany, but it is found also, in combination with soda, in some parts of Thibet.

Rivers have their origin in springs, glaciers, or lakes. Sometimes the source of a river may be determined without difficulty, as that of the Ganges, for example, which issues as a broad stream from a huge ice cavern. In most cases, however, the head waters of a river consist of a number of streams, and it is next to impossible to select any one as the real source. Dr Livingstone describes the sources of the Lualaba as a perfect network of streams rising out of a spongy soil. The course which a river will take depends upon the general slope of the country. Gradually the several streams draining this slope are taken up by one channel, and the river winds its way

to the sea, augmented from time to time by the feeders which join it on either hand. The whole area drained by a river and its tributaries is called the *river-basin*. The term "catchment-basin," sometimes met with, applies to that part of a river-basin from which rain is collected, and does not always—as in the Nile, for example—coincide with the river-basin.

The line which separates one river-basin from another is termed a *watershed*, or water-parting. Some writers apply the term watershed to the slope down which the streams flow; but this use of the term is evidently incorrect, as the word is adopted from German geographers (*wasserscheide*), and means water-separation. The line of watershed is not necessarily a ridge of high ground. In some instances the feeders of a river rise at no great elevation, and in their course towards the main stream pass through those hill ranges which at first sight seem to form the watershed. This is especially the case in those parts of England where chalk ranges are found. Occasionally the line of water-parting is so level that the upper streams of independent rivers mingle together. Thus the Cassiquiare, a feeder of the Orinoco, has communication with the Rio Negro, a tributary of the Amazon. In South Africa, the small lake Dilolo is said to send out streams which flow into the Zambesi on the one hand, and into the Congo on the other. We have an example, also, in Norway: the small lake Lessoëvark, which lies at the summit of the Dovrefield, at an elevation of 2000 feet, has a stream issuing from each end, one of which forms the Logen, a feeder of the Glommen, and the other flows through the valley of Romsdaal into the Atlantic.

Rivers which have their sources within the tropics rise and fall periodically with the recurrence of the rainy season: the Nile affords a well-known example. In temperate regions the floods are irregular, and some streams, like the St Lawrence, vary very little in the volume of water discharged in the course of a year. A great deal depends upon the nature of a river's source and upon the character of its basin. If a river rises in a

glacier, or is fed by mountain snows, its supply is kept up in summer, when otherwise it would suffer from drought. Lakes, again, form what are termed, "flood moderators." A large drainage area has something of the same effect as lakes in keeping up a regular supply, since the droughts in one part of the basin may be counterbalanced by floods in another part: the Amazon is an example. Something also depends upon the nature of the surface drained. Where the subsoil is gravel, chalk, or limestone, a great portion of the rainfall is absorbed, and floods do not occur until the ground has been thoroughly saturated. Where the soil is less absorbent, especially in smaller streams, a flood succeeds almost every rainfall.

The channel in which a river flows has been scooped out by the river itself, and sometimes large valleys have been formed in this way. In some desert tracts, as in Turkestan and in the interior of Australia, for example, the rivers have no proper channels. After heavy rains they overflow and spread their waters over a large extent, forming marshes and shallow lakes; while in the dry season they consist of a mere succession of pools. At some future time they may have worn channels deep enough to keep up a perennial supply of water: in the meantime the floods irrigate the waste lands which lie around. The solid matter which a river scoops out of its bed is disposed of in various ways: some portion may be used in filling up a lake; another portion may help to form a delta at the outlet of the river; while a considerable portion is always carried down to the sea. We have in a previous chapter referred to the important work performed by the action of rivers upon the earth's surface (p. 65).

If we glance at a map of the world, or examine an artificial globe, we cannot but notice how many rivers flow into the Atlantic Ocean, and how very few into the Pacific; and when we recollect the important influence which large rivers have upon civilisation, this distribution would seem to point out the Atlantic as the great centre of civilisation in the future, as the Mediterranean was in ancient times. It is curious, also, to notice that by far the greater number of the

important rivers on the globe flow in an easterly direction; those which flow to the north and south being next in number, while very few large rivers flow westward. This is, of course, owing to the structure of the continents and the disposition of the mountain chains.

Inland Basins.—Some streams never reach the ocean either directly or indirectly. This is especially the case in Eastern Europe and Central Asia. Thus the Volga and the Ural River empty themselves into the Caspian, which has no outlet; the Oxus and Sir-Daria into the Sea of Aral; the Tarim into Lake Lob; and the Helmund into Lake Zurrah. The Caspian and Sea of Aral occupy a great depression in the surface of the globe: the Sea of Aral is only 40 feet above the level of the ocean; while the Caspian is far below it. It is very probable that at no distant period the Sea of Aral, the Black Sea, and the Caspian, with the intervening land, were covered by a large body of water. Owing probably to excessive evaporation, caused by the extreme dryness of the air, this large sea has in parts been dried up, and hence we may perhaps account for the numerous small salt lakes which abound in this region. A large portion of Northern Africa, occupied by the desert of Sahara, is destitute of rivers; but to the south lies Lake Tchad, which receives several streams, though it has no outlet. The whole interior of Australia is destitute of anything deserving the name of river, though creeks are numerous. In North America the Great Basin of Utah has an inland drainage, and in South America the plateau of Titicaca and some other portions of the Andes have also inland drainage areas.

Lakes have been classed in four groups, which it may be convenient to notice:—

1. Those which neither receive nor send out streams. Such lakes are very rare, and are generally small. In the Ural Mountains and in the basin of the Obi there are several of these, some of fresh and some of salt water. The former are doubtless fed by springs; the latter are probably the remains of an ancient arm of the sea which once filled the hollow now drained by the Obi. Lakes of this kind also

sometimes occupy the craters of extinct volcanoes. Such a lake is the picturesque Albano, in the neighbourhood of Rome, which is about six miles in circumference, and is surrounded by villas and olive-gardens.

2. Lakes which receive streams, but do not discharge any. Many examples are met with in Asia, but we need only mention the Caspian, the Sea of Aral, Lake Balkash, the Dead Sea, Lake Zurrah, and Lob Nor. Africa furnishes us with an example in Lake Tchad; and in North America the Great Salt Lake belongs to this group. In all lakes of this kind the surplus water must be carried off either by evaporation or by underground channels. Where the excess is carried off by evaporation the lake is generally more or less salt. For every stream that enters it carries into it a certain amount of saline matter; and as only pure water is evaporated, the water that is left must in time lose its freshness.

3. Lakes which receive no feeders, but which discharge streams. In this case the lakes must be fed by springs, and the springs must be sufficiently copious not only to counterbalance evaporation, but to keep up a perennial stream. We have examples in Sir-i-Kol, the source of the Oxus; Seliguer, the source of the Volga; and Itasca, the source of the Mississippi. Sir-i-Kol, or Lake Victoria, as it is sometimes called, lies in the plateau of Pamir, at an elevation of 15,600 feet, and is said to be the most elevated sheet of water upon the globe.

4. By far the most numerous class of lakes includes those which both receive and discharge streams; and these are often mere expansions of the river-bed. We have stated in a previous chapter that, in the opinion of Professor Ramsay and others, the rocky basins of many lakes have been hollowed out by glacier action; and it is certainly a remarkable fact that, both in the Old and New Worlds, those parts of the northern continents which during the Glacial period were covered with glaciers now contain the most lakes. In the Lake district of Cumberland and Westmoreland, in Killarney, and among the lakes of Wales and Scotland, distinct traces of glacier action are met with.

The most intensely salt of all known lakes is Elton, in the steppes east of the Volga, and about 160 miles south-east of Saratov. It has an area of 130 square miles, but the depth is nowhere more than about 15 inches. About 3,500,000 cwts. of salt are collected annually from its waters, as well as large quantities of hydrochlorate of magnesia. It is probably one of the remains of the vast inland sea which united the Caspian with the Sea of Aral, and is now almost dried up. Next to Lake Elton comes the Dead Sea, with its intensely bitter waters. It occupies a remarkable depression 1312 feet below the level of the Mediterranean. There are several salt lakes in Persia: in the north-west is Urumiah, 300 miles in circuit. Its waters, which are perfectly clear, contain one-fourth of their weight of saline matter, and fish cannot live in them. The waters of the Great Salt Lake, in the territory of Utah, are also too salt to support animal life. The lake receives the Bear, the Utah, and several other streams, but has no outlet. The Lake of Assal, on the east coast of Africa, nearly opposite Aden, is interesting as showing how lakes are sometimes formed. Its surface is 570 feet below the level of the sea, and it has a circumference of 16 miles. It is separated from the Gulf of Aden, of which it once doubtless formed a part, by a barrier of lava raised by volcanic agency at a comparatively recent period.

CHAPTER IX.

THE OCEAN.

The Ocean occupies three-fourths of the entire surface of the globe. This large mass of water is divided into several parts by the great land masses, and to each division a distinctive name has been given.

The *Pacific*, the largest of these divisions, is bounded on the east by America, on the west by Asia and Australia. It is somewhat oval in shape, but widens considerably towards the south. Its eastern shore is rocky and continuous; its western shore, which is not so high, is indented with large land-locked seas. We have already mentioned that the whole shores of the Pacific are volcanic. The length of the ocean from north to south is about 10,000 miles; its greatest breadth is nearly as much; and its total area has been estimated at 90,000,000 square miles, so that it covers nearly one-half of the entire surface of the globe.

The *Atlantic Ocean*, extending between the Old and New Worlds, is equal to the Pacific in length, but is comparatively narrow, its widest part being not more than 3600 miles across. It has been remarked that this ocean is valley-like in shape, the opposite sides corresponding to each other. The northern half of the Atlantic contrasts with its southern basin in its abundance of land-locked seas. On the east we have the Baltic, German Ocean, and the Mediterranean; on the west, Hudson Bay, the Gulf of Mexico, and the Caribbean Sea. Its shores contrast with those of the Pacific in being, in general, low and sloping, and hence it receives the drainage of a great part of the dry land. Its area is about 25,000,000 square miles.

The *Indian Ocean* is triangular in shape, but the apex

of the triangle is split in two by the peninsula of Hindostan. Its total area is about 23,000,000 square miles. Of the *Polar Oceans* very little is known, but they seem to be covered for the greater part of the year with ice of unusual thickness. The Arctic Ocean is supposed to have an area of about 3,000,000 square miles, and the area of the Antarctic Ocean may be considered about the same.

Arctic Regions.—Considerable interest attaches to the Arctic Ocean, owing to the various attempts that have been made to discover a passage from the Atlantic to the Pacific in high latitudes, and the efforts to reach the North Pole. The honour of having discovered the north-west passage may be shared between Sir Edward Parry and Captain M'Clure. The former, in 1819, pushing through Lancaster Sound and Barrow Strait, succeeded in reaching the northern shore of Banks Land; and thirty years later, Captain M'Clure, in his voyage from Behring Strait, succeeded in reaching the southern shore of the same island. But no vessel has yet accomplished the whole passage. The north-eastern passage has, however, been achieved by a Swedish vessel, the *Vega*, which left Gottenburg in July 1878, and, after circumnavigating the continent of Asia, returned home by the Suez Canal in the spring of 1880.

In the year 1875 Sir George Nares succeeded in navigating the *Alert* to the northern extremity of Robeson Channel. Here the land on the American side stretches away, first to the north-west and then to the south-west, for a considerable distance; and in this stretch of coast stands Cape Colombia (lat. 83° 7′), the most northerly point of land at present known. The coast of Greenland, on the opposite side of the channel, attains almost as high a latitude. In the spring of 1876 an attempt was made to reach the Pole by means of sledges; but after reaching the latitude of 83° 20′ 26″ the attempt was abandoned. Instead of an "open Polar Sea," ice of an unusual thickness was met with. In ordinary cases the ice of the Polar regions is from 2 to 10 feet in thickness; but here, in consequence of there being so few outlets for it to escape

southward in any appreciable quantity, the ice gradually increases in age and thickness until it measures from 80 feet to 120 feet, floating with its surface 15 feet above the water line. When two pieces of ordinary ice are driven one against the other and the edges broken up, the crushed pieces are raised by the pressure into a wall-like edge. When two of the ancient floes of the Polar Sea meet, the intermediate and lighter ice alone suffers. It is pressed up between the closing masses to a great height, producing a chaotic wilderness of angular blocks of all shapes and sizes, sometimes rising 50 feet in height, and frequently covering an area a mile in diameter. Owing to this extraordinary character of the ice, a roadway had to be formed by pickaxes for nearly half the distance travelled. The advance was consequently very slow, and only averaged about a mile and a quarter daily. Success under these circumstances was clearly impossible.

Antarctic Regions.—Very little is known of the region round the South Pole. Sir James Ross, who commanded the expedition sent out by the British Government in 1839 to ascertain the position of the south magnetic pole, discovered Victoria Land, which, from its extent, seems to form part of a continent. The northern coast forms perpendicular ice-cliffs from 200 to 500 feet in height, and stretching for miles to the east and west. In the parallel of 77° Mount Erebus was discovered, enveloped in ice and snow from its base to its summit, from which arose a dense column of black smoke. Its height above the sea is 12,369 feet; and Mount Terror, an extinct volcano near it, reaches an altitude of nearly 11,000 feet.

The *Challenger*, in its voyage round the world, penetrated for some distance within the Antarctic circle, and met with numerous icebergs. All these were tabular in form, with perpendicular cliffs rising, on the average, about 200 feet. Some were two or three miles in extent, and as many as eighty were counted at one time. They were all distinctly stratified, the layers being several feet in thickness near the top, and, gradually diminishing to

mere lines near the water's edge. The upper layers were mostly of snow; a cannon ball fired into one berg, about 50 feet from the top, sank into it without producing and visible effect; but one aimed at the same mass near the water line broke away vast masses of solid ice with a conchoidal fracture. The ice-cliffs were frequently of a beautiful pale blue colour, except where the water had hollowed out a cave, and then the tint was deeper. Sir Wyville Thomson describes one iceberg which he saw as gable-shaped, "with a glorious blue Gothic arch in the centre, and a separate spire over 200 feet high. It was like a gorgeous floating cathedral, built of sapphire set in frosted silver."

Depth of the Ocean.—An opinion at one time prevailed that the depth of the ocean was comparable with the general elevation of the continents, and that the deepest soundings would be found to equal the highest points on the land. In one respect this opinion has been confirmed. The greatest depth ascertained by the *Challenger* was in the western part of the Pacific, a little north of the Caroline group, where the sounding line indicated 4575 fathoms, or a little over 27,000 feet. American naval surveyors record a depth of 30,000 feet off the east coast of Japan; and we know that the height of Mount Everest is 29,000 feet. But, on the other hand, it must be borne in mind that while the average elevation of the land is not more than 1000 feet, the average depth of the ocean is probably twelve times as much. A great part of the North Atlantic has a depth of 2000 fathoms, while the average depth in the North Pacific is probably 1000 fathoms more.

The apparatus used by the *Challenger* in ascertaining the depth of various parts of the ocean, and the nature of the deposits which covered the ocean floor, consisted of a long cylinder, about two inches in diameter, attached to a strong sounding-line. Round the line three or four "sinkers"—according to the supposed depth—were arranged and held in position by a strong wire, which is passed over catches at the upper end of the cylinder. The tube is made to project about eighteen inches beyond the

sinkers, and on striking the bottom the wire detaches itself from the catches, and the sinkers drop off. The tube in the meantime has sunk several inches into the clay or mud which covers the ocean floor, and when drawn up a specimen of the ocean deposit is obtained. Attached to the sounding-line are thermometers, duly protected against pressure, to register the temperature at various depths, as well as pressure-guages and a water-bottle. The water-bottle is a heavy metal cylinder, so constructed that it shuts up when it reaches the bottom, and thus encloses a specimen of the water. There is a small opening in the upper part to allow some of the water to escape, otherwise the bottle would burst on being drawn up, owing to the greatly diminished pressure on the outside as it approached the surface.

Besides the sounding-line with the instruments attached to it, trawls, dredges, and tow-nets were also used for the purpose of catching specimens of the small plants and animals which live at various depths. The trawl is a long beam of timber to which a net is attached. The dredge is of similar construction, but beneath the net there is an iron rod supported by strong ropes, and to this rod large hempen tangles or "swabs" are fixed, which frequently catch up anything the net has missed. The two nets were made of muslin or cloth, and were dragged through the surface waters, and thus thousands of organisms which live at or near the surface were captured.

It is very probable that the great ocean beds are all diversified by hill, valley, and plain, just as the surface of land is, though the effect of marine denudation and oceanic deposits is to smooth rugged peaks and to fill up hollows. The bold cliff, the hollow glen, and the picturesque mountain summit which lend a charm to land scenery are the effects of aerial denudation, and can scarcely have their counterpart at the bottom of the sea; but ridges and elevations of considerable altitude are met with. In the Atlantic a submarine ridge running parallel to the shores of the ocean has been traced from Greenland as far south as Tristan

d'Acunha, and from its crest rise up various summits, which appear above the surface of the ocean in the Azores, St Paul's Rocks, and Ascension Island. The average depth of water upon the ridge is about 1600 fathoms, but on each side of it there are valleys of much greater depth. South of the equator the ridge is called the "Dolphin Rise," in compliment to the American ship which first surveyed it, and the depth of the western valley reaches 3000 fathoms. In the North Atlantic the general depth is considerably less, and the eastern valley may be said to end in the neighbourhood of the Faroe Islands. There is a depth of 3000 fathoms, however, immediately to the west of the Cape Verde Islands, and the depth of 3875 fathoms has been recorded about fifty miles north of the island of St Thomas.

A branch from the central ridge runs off towards the West Indies, about the parallel of 10° north, and thus divides the western valley of the Atlantic into two parts. Such transverse ridges, as we shall afterwards see, have considerable influence upon the distribution of temperature in the waters of the ocean. The bed of the Pacific is not so well known as that of the Atlantic, but submarine ridges are known to exist in various parts. One of these probably bounds the Coral Sea on the east; another connects the Friendly Islands with Fiji and the New Hebrides; while a third runs northward from Fiji in the direction of the Caroline and Ladrone Islands.

Ocean Deposits.—The deposits which cover the ocean floor are of various kinds, and derived from various sources.

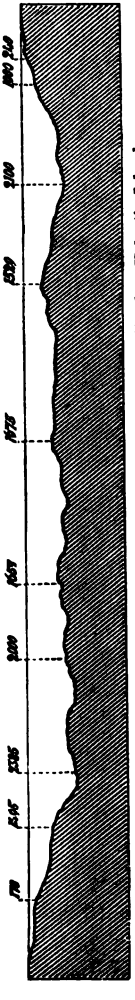


Fig. 6.—Section across the Atlantic from Trinity Bay, Newfoundland, to Valentia Island.

For a distance of about two hundred miles from land we meet with shore material—that is, sand and clays derived from the detritus carried down by rivers or formed by the action of the waves upon the land. Beyond that limit the deposits consist for the most part of the remains of plants and animals which live in the ocean. Thus over a great part of the North Atlantic we find what has been termed the *Globigerina ooze.* It consists almost entirely of the shells of minute Foraminifera, belonging principally to one genus—the Globigerina. It is now ascertained that the Globigerinæ live at or near the surface of the water, and that when alive they are about the same specific gravity as water, their weight being reduced by small oil globules scattered through their substance. When they die the oil disappears, and their shells slowly sink to the bottom. The ooze, when dry, resembles fine sago; and as it consists almost entirely of carbonate of lime, it is not improbable that in these deposits we have the material of future beds of limestone or chalk.

The Globigerina ooze is seldom met with at a greater depth than 2000 fathoms. When that depth is reached, the minute shells seem decayed and yellow, and at a depth of 2500 fathoms they disappear entirely, and their place is taken by a red clay. This clay, which consists of the silicate of alumina and iron, is probably the most extensive of all the oceanic deposits, but its origin is very obscure. In many parts of the ocean, where the depth exceeds 2000 fathoms, the Globigerinæ are as numerous near the surface as elsewhere, yet not a trace of their shells can be found in the mud which covers the ocean floor. What becomes of the shells, and what is the origin of the red clay? Mr Murray, one of the naturalists attached to the *Challenger*, supposes that at great depths the shells are entirely dissolved by the carbonic acid which the sea water contains. This dissolving will always take place to some extent; but when the depth exceeds a certain point the shells entirely disappear. He thinks the red clay has a volcanic origin, and that it is decomposed pumice-stone.

The Pacific, we know, is fringed with active volcanoes; and though the shores of the Atlantic are almost free from them, yet there are active volcanoes in many of the islands. Besides this, submarine volcanoes are not uncommon. Pumice-stone, which has been aptly termed "the froth of lava," is very light, and may be carried to a considerable distance by winds and waves. In almost all parts of the sea the *Challenger* met with pumice floating about, and the trawl or the dredge frequently brought up bits of pumice which, after floating for a certain time, had become water-logged and sunk. Now, the carbonic acid of the ocean water acting on the felspar in these pumice-stones decomposes them. The lime and magnesia are taken up by the water, and the residue is the silicate of alumina. What seems to strengthen this theory is that in the red clay crystals of quartz and other minerals are met with, and the same crystals are found in the floating pumice-stones.

It is evident, if this theory be correct, that either the red clay or the undecomposed pumice ought to be found in all parts of the ocean; and probably this is the case, only that in shallower parts the clay is covered by the Globigerina ooze or some other deposit. In connexion with this subject we may mention that Mr Buchanan, another of the naturalists belonging to the *Challenger*, proved that the red clay, to some extent at least, is derived from the shells of the Foraminifera. Taking a sample of the ooze from the neighbourhood of St Thomas Island, he subjected it to a weak acid, and the result was that the carbonate of lime disappeared, and a residuum—about one per cent.—of red clay, identical in composition with that found in the ocean, remained.

The red clay is found over the greater part of the bottom of the Pacific, and in many parts it is intermixed with nodules composed of nearly pure peroxide of manganese. These nodules vary in size from a canary seed to an orange, and almost all of them contain as a kernel in the interior a shark's tooth, the ear-bone of a whale, or a fossil of some kind, which has formed the nucleus

round which the manganese has accumulated. It is not improbable that the manganese is also obtained from the disintegration of volcanic products.

In some parts of the middle and western Pacific the red clay is covered with patches of a siliceous deposit called the *Radiolarian ooze.* The Radiolaria are minute organisms with siliceous instead of calcareous shells. They seem to live at all depths, and hence their shells are not destroyed before reaching the bottom. This siliceous deposit is only found at very extreme depths. In the Southern Ocean, where the depth is not so great as in the Pacific or Atlantic, the surface of the ocean is covered with a set of minute plants which have siliceous coverings. These *diatoms*, as they are called, live on the surface, and when they die their remains drop to the bottom of the ocean and form a white deposit, which looks at first extremely like chalk, though it is formed entirely of silica.

It thus appears that if we arrange the various oceanic deposits according to the depths at which they are found, we shall have, first, shore deposits in comparatively shallow water; then a siliceous deposit in the Antarctic Ocean, formed by the remains of plants; next, the Globigerina ooze, formed from the calcareous shells of a minute Foraminifera; then the red clay arising from decomposed volcanic products; and lastly, the Radiolarian ooze, a siliceous deposit formed out of the shells of the Radiolaria.

Colour of the Sea.—The colour of the open sea is a deep blue, passing into a green as the water becomes shallower. It is probable that blue is the natural colour of pure water, but this colour is modified sometimes by particles of matter held in solution. In mid-ocean the colour is almost black, owing to the amount of sunlight absorbed by the great depth of water. In the Red Sea, the Vermilion Sea, and off the mouth of the La Plata, the water is coloured by infusoria. The sea is white in the Gulf of Guinea, dark purple in the Black Sea, green in the Persian Gulf, and yellow off the coast of China. The waters of the Yellow Sea are discoloured by the mud brought down by the great Chinese rivers. The colour of clear shallow water depends

upon the bottom: over white sand it is green; brown or black over a dark ground; and gray over mud.

Animal life exists at all depths in the ocean, but plant life is found only at or near the surface. Sunlight only penetrates to a certain depth. It is probable that all is dark below 200 fathoms, excepting in so far as light is given out by phosphorescent animals. Very many of the deep-sea animals are blind, while others have well-developed eyes. It has been suggested that the ocean depths are lighted up here and there by greater or smaller patches of luminous organisms, with wide intervals of darkness intervening, and that possibly those animals which have eyes congregate round the sources of light. In those dark waters where the temperature is only a little above the freezing point it is not surprising that animal life should be scarce; and yet those beautiful siliceous sponges, such as Venus's flower-basket and the glass rope sponge, extend all over the sea bottom. One drawback to the existence of animal life is the want of food. In the absence of plants, the deep-sea animals have to depend upon the little animal and vegetable matter remaining in the shells and exuviæ which have fallen from the surface to the bottom. Animal life is more abundant in the organic oozes than in the red clay. Some food is also doubtless obtained from the refuse of various kinds washed down by rivers or floated out from shores to sea, which, on becoming waterlogged, has sunk to the bottom.

CHAPTER X.

Oceanic Currents.

Salts of the Ocean.—The bitter taste of sea water is owing to the mineral ingredients which it contains. It has been estimated that the solid matter held in solution by sea water is three and a half per cent. of its weight, or, more accurately, 34·4 parts in a thousand. Of this percentage about 24 parts are chloride of sodium, or common salt; about 4 parts are chloride of magnesium; an equal quantity is sulphate of soda; one part in a thousand is carbonate of lime; and only ·25, or one part in four thousand, silica. Beside these principal constituents, there are about twenty other elementary substances found to a less extent. The mineral matter absorbed by the countless inhabitants of the ocean in order to build up their shells and skeletons is returned to the sea in the solid matter brought down by rivers, in the salts which fresh water always contains in greater or less abundance, and probably also, as we have seen, in the decomposition of volcanic products.

The constituents of sea water are everywhere the same, but the amount of these constituents varies occasionally from local causes. The proportion of salt is smaller in the Polar oceans, owing to the melting of the ice in summer, and probably also to the excess of precipitation in the form of rain and snow. On the other hand, the trade-wind region is above the average in saltness, owing to excessive evaporation. The water in the Southern Ocean, for the same reason, is more salt than in the North Atlantic. The Pacific is also less salt than the Atlantic: this may probably be owing to the fact that there are fewer rivers to supply the salts extracted from its waters by the corals and fishes which abound in that ocean. The water of the Baltic is

only brackish: this is doubtless owing to its shallowness, and to the large quantity of fresh water poured into it. The Mediterranean and the Red Sea, on the other hand, owing to excessive evaporation, are of greater specific gravity than any part of the open ocean.

Temperature.—The investigations carried on by the *Challenger* show some curious results in connexion with the distribution of temperature among the waters of the ocean. The surface water, down to a depth of about 500 fathoms, is affected by the latitude of the place, the season of the year, and ocean currents. Below this surface water there is a temperature of about 40° or 45°, and gradually as the depth increases the temperature falls until it reaches the freezing point of fresh water, or even a point below it. In the temperate parts of the North Atlantic we descend at least a mile before we meet with a temperature of 40°, while in the tropical and south temperate regions of that ocean, curiously enough, we only require to descend about half a mile to reach a similar temperature; and this is the case with the tropical and temperate parts of the Pacific. It is very probable that the Gulf Stream is the cause of the exceptionally high temperature of the North Atlantic. It has been found in this current that, down to a depth of 300 and 400 fathoms, the temperature is still 60° Fahr. Of course, as we approach the Polar regions, the temperature of 40° is met with at the surface.

It appears, then, that we have a very uniform and at the same time a very low temperature at the bottom of the sea: quite under the equator water has been obtained with a temperature of only 32°·7. Sir Wyville Thomson believes that there is a flow of cold water from the Southern Ocean, and this is rendered probable by the following facts:—Sometimes it has been observed that the temperature decreases gradually from the surface to the bottom; in other cases it decreases to a certain point, and then remains uniform to the bottom. The explanation is that the lower and colder water, in its course from the south, meets with a barrier—a submarine ridge—which stops it. The basin beyond, therefore, is filled with water of the

same temperature as that on the top of the ridge. Thus there is free connexion between the Southern Ocean and the western valley of the South Atlantic; the consequence is that along the east coast of South America we meet with a bottom temperature of 31°; but in the two basins of the North Atlantic, which are protected by the submarine ridges from the southern flow of cold water, we have at the bottom, and from a depth of about 2000 fathoms down to the bottom, a temperature of 35°. The Coral Sea is filled with water which has a uniform temperature below 1400 fathoms; while in such enclosed areas as the Sulu, Banda, Celebes, and China Seas the minimum temperature is met with at 900, 700, or even 500 fathoms. The depth at which this temperature is reached points out the depth of the lowest point of the ridges which separate the waters of these basins from the outer ocean.

Many theories have been advanced to account for the northward flow of the cold Antarctic waters. Dr Croll thinks it but part of a general ocean circulation, originated and kept up by the action of the prevailing winds. Dr Carpenter thinks it is owing to the great pressure of the mass of cold water in the Southern Ocean. Sir Wyville Thomson thinks the circulation is owing to the fact that there is an excess of evaporation in the northern hemisphere, while in the Southern Ocean there is an excess of precipitation, and that there is consequently a movement of the water northward to restore equilibrium. It will be seen that this theory agrees with that of Dr Carpenter so far as to attribute the movement of the water to differences of pressure: in the one case, however, the pressure is said to be owing to a lower temperature, while in the other it is attributed to excess of precipitation. There is probably some truth in both theories. The question, however, is a large one, and opens up the whole theory of ocean circulation and the origin of oceanic currents.

Oceanic Currents.—Great differences of opinion have existed at various times with respect to the cause of oceanic currents. Some eminent geographers attribute them solely to the influence of prevailing winds, while

others trace their origin to the disturbance of equilibrium caused by the heat of the tropics. Doubtless both these causes operate. The permanent and periodical winds, blowing for a long period in the same direction, must have some effect upon the waters over which they pass, and currents of greater or less depths will result. On the other hand, were there no winds whatever, there would still be oceanic currents. In fact, the same cause—the heat of the sun—which produces a circulation in the atmosphere must necessarily produce a circulation in the ocean. The waters within the tropics being greatly heated, two things result: the tropical waters are expanded, and consequently become of less specific gravity; and, secondly, considerable evaporation takes place. To supply the waste of the water which has been evaporated, and at the same time to restore the general equilibrium, cold currents will flow in from the poles. These polar currents will necessitate return currents, and all will be affected by the rotation of the earth. Thus, as with the winds, we might expect a cold current from either pole, an equatorial current, and return currents to the poles. The fact that these currents coincide in many instances with the direction of the winds ought not to blind us to their independent origin.

There is another way in which the equilibrium of the waters of the ocean may be disturbed, which should not be overlooked. When evaporation takes place to a considerable extent, the water left behind, being more salt, has a greater specific gravity, and therefore sinks; and this downward motion produces a circulation. This is well illustrated in the case of the Mediterranean. It has now been conclusively proved that a surface current flows from the Atlantic through the Straits of Gibraltar; and that beneath this there is another current, containing a large percentage of salt, which sets outward. The water from the Atlantic flows in to supply the waste caused by evaporation: at the same time the greater density of the Mediterranean disturbs the equilibrium between the columns of water at the two extremities of the Strait, and

there is an outflow of denser water through the Strait to restore equilibrium. The outflow is an under-current, owing to the water being of greater specific gravity. In the Red Sea there are similar currents, owing to the same cause—excessive evaporation. In the Baltic, on the other hand, the outflow is on the surface. Owing to the quantity of fresh water which that sea receives from the numerous rivers which discharge into it, its waters are less dense than those of the Atlantic, and there is an outward current through the Sound, the Great Belt, and Little Belt into the German Ocean; and there is a return under-current of salter water from the German Ocean.

It appears, therefore, that in the difference of density—caused either by a difference of temperature or difference in amount of salinity, or perhaps, as Sir Wyville Thomson suggests, caused by merely mechanical pressure—we have a power sufficient to cause a circulation in the waters of the ocean, quite independent of the agency of the winds, though doubtless the winds assist the circulation, and in some cases give rise to drift currents.

Dr Carpenter, who believes that the general oceanic circulation depends upon differences of temperature, lays more stress upon the effect produced by polar cold than that by tropical heat. The effect of the surface heat upon the waters of the tropical basin, he contends, will be for the most part limited to its uppermost stratum; while the effect of surface cold upon the waters of the polar basin will be to reduce the temperature of the whole mass. The surface stratum will sink as it is cooled, in virtue of its increased density, and will be replaced by water not yet cooled to the same degree. Thus a circulation between the poles and the tropics is commenced, the cold current being an under-current, the warmer current being on the surface.

This theory seems borne out by the fact that, during the cruise of the *Lightning* in 1869, distinct evidence was collected of the existence of cold under-currents proceeding from the north; and the northward flow from the Antarctic basin still further strengthens it. On the other

hand, the theory fails to explain the existence of the cold surface-currents, which are met with in the North Atlantic and in other parts. These seem to imply that the initial disturbance takes place at the tropics, and that these polar currents move towards the equator to restore equilibrium. At first they are surface-currents; but on meeting with water of higher temperature, and therefore less density, they become under-currents. The truth seems to be that both causes—polar cold and tropical heat—are operative at the same time.

We have endeavoured thus generally to explain the cause of oceanic currents; we next proceed to describe them in detail. It is evident that they will be much more affected by the distribution of land than the winds are; but still we shall be able to trace their normal character.

Commencing with the Pacific Ocean, we find that in the great southern basin, besides the northward flow of cold water which can only be detected by the sounding apparatus, various cold currents flow on the surface from the Antarctic Ocean. One of these washes the southern coast of Australia; another reaches Cape Horn. The latter divides, one branch flowing round the Cape to the east, while the other proceeds up the western coast of South America, and at length mingles its waters with the great Equatorial Current. The current which washes the west coast of South America is called the Peruvian or *Humboldt's Current.* It is much colder than the waters of the neighbouring ocean, and off Lima the difference in temperature is said to amount to 20° Fahr. The *Equatorial Current* sweeps across the Pacific with a speed ranging from 30 to 35 miles a day, and extends in a broad belt on each side of the equator with a breadth of about 50°. It is to be noticed that though the trade-winds do not blow with great regularity over the western half of the Pacific, the Equatorial Current is fairly steady, and this would seem to militate against the theory that in all cases the currents depend upon the winds.

On reaching the chain of islands which stretches between Asia and Australia, the Equatorial Current is broken up

into several channels, and struggles through into the Indian Ocean. In the northern part of this ocean the current is influenced by the monsoons, but a portion continues its course to the west, and strikes upon the island of Madagascar. Here it divides, one branch rounding the northern extremity and flowing south through the Mozambique Channel, the other flowing south-west towards the Cape of Good Hope. Off the Cape, a large sandbank—the Agulhas Bank—has been formed, stretching more than 500 miles from east to west, with an average breadth of 100 miles. Between this bank and the mainland the *Cape Current* flows, and on entering the Atlantic it is met by another current which sets in from the north-west. It therefore divides: a part returns with the Atlantic Current into the Indian Ocean, while the other part flows north-west along the western coast of Africa and joins the great Equatorial Current of the Atlantic.

The Atlantic Equatorial Current flows from the Gulf of Guinea across to the continent of South America, which it strikes in the neighbourhood of Cape Roque. Here, owing to the trending of the coast, it divides into two branches: one turns southward along the coast of Brazil, while the other follows the north coast of South America, and, having passed the shores of Guiana, enters the Caribbean Sea. A branch of the Brazil Current, probably aided by the return winds, flows south-east, and, under the name of *South Connecting Current*, re-enters the Indian Ocean; while another branch, as we have already noticed, meets the Cape Current on its entrance into the Atlantic. The Guiana Current, after passing round the Caribbean Sea, follows the shores of the Gulf of Mexico, and emerges through the narrows of Bemini under the name of the Gulf Stream.

The *Gulf Stream* can be easily distinguished from the waters of the surrounding ocean by its deep indigo colour, its high temperature, and its speed. These characteristics are doubtless owing to its waters having made the circuit of the Gulf of Mexico under a tropical sun, and to the outlet being comparatively narrow. The breadth of the current in the "narrows" is about 32 miles, and its velocity

from two to four miles an hour. Its depth is very considerable, as there is little change of temperature at a depth of 3000 feet. Its surface temperature in the Strait of Florida is from 80° to 84°, according to the season. On emerging from the Gulf the warm waters gradually rise and spread themselves over the surface. Off Cape Hatteras the breadth of the current is more than twice the width in the "narrows," and as it proceeds in its north-easterly course it widens very considerably; it becomes much more shallow, and its speed, in the latitude of New York, is not more than one mile per hour. South of Newfoundland the Gulf Stream loses all its special characteristics as to warmth, colour, and flow, and it dies away into the sluggish Atlantic Drift that sets in a north-easterly direction. The southern portion of this "Drift" reaches the Azores, and then, turning southward, finally mingles with the Equatorial Current off the Coast of Guinea. The northern portion, sometimes called the *Gulf Stream Drift*, bathes the shores of the British Islands, proceeds along the coast of Norway and to the eastward of Spitzbergen, and finally mingles with the waters of the Arctic Ocean.

It would appear, then, from what has been said, that if the Equatorial Current of the Atlantic had a free passage into the Pacific, there would be no Gulf Stream; and that, as it is, the Gulf Stream properly so called ends in the latitude of Newfoundland. The Drift, which still proceeds to the north-east, is the natural flow of the warmer waters of the tropics to the polar basin, and would exist were there no Gulf Stream whatever, for the same reason that we have south-west winds. It is quite possible, however, that the Gulf Stream may add increased vigour and increased temperature to this northern flow.

Two important *Polar Currents* may be traced in the North Atlantic: one flows along the east coast of Greenland, and the other down Baffin's Bay and Davis Strait. They meet south of Cape Farewell, and the united stream washes the coast of Newfoundland, and is felt as far south as New York. The water of this current, being cold and heavy, gradually sinks as it moves southward, and con-

tinues as an under-current. Thus it is that large icebergs are sometimes carried as far south as the 40th parallel. The meeting of the tropical and polar currents in the neighbourhood of Newfoundland is curious: the struggle between the two is so strongly marked that the interlacing of the warm and cold waters, as indicated by the thermometer, has been compared to the clasped fingers of the hands. Farther south, where the Gulf Stream is stronger, the division between the tepid waters and the cold current flowing on its western side is well marked. Off the coast of Massachusetts the line of separation has been termed the "cold wall," so nearly perpendicular and well defined to great depths is the division.

Japan Current.—A warm current which bathes the east coast of Asia bears some resemblance, in its character and direction, to the Gulf Stream of the Atlantic. It flows from the Indian Ocean through the Straits of Malacca, turns to the north-east between Borneo and the coast of China, and, being joined by a portion of the great Equatorial Current of the Pacific, flows northward along the east coast of Japan and enters the Sea of Kamtchatka. A branch of the current now passes through Behring Strait into the Arctic Ocean, but the greater portion of it sweeps past the Aleutian Islands and down the west coast of North America. By the time this current has reached California, in its progress to the south, it has lost much of its warmth, and imparts a refreshing coolness to the sea-breezes of that coast in summer time.

As Behring Strait is too shallow to admit of under-currents, there is no cold current through it corresponding to the current on the east coast of Greenland; but the current which flows down Davis Strait has its counterpart in a cold current from the Sea of Okhotsk, which washes the west side of the Japan Islands and flows southward along the coast of China. The cold current which traverses Baffin's Bay is fed by two ice-streams, one of which comes from Smith's Sound, and the other from Parry Islands and Lancaster Sound. The existence of the latter was proved in a remarkable manner. An English vessel, the *Resolute*,

having been abandoned in the neighbourhood of Parry Islands in 1854, was picked up the following year by some American whalers in Baffin's Bay.

A glance at the map will show that the surface-currents of the ocean have a tendency to flow in curves, enclosing spaces of still water. We have an example of this in the *Sargasso Sea* of the North Atlantic, lying between the Gulf Stream and the Equatorial Current. It covers a space as large as the basin of the Mississippi, and is so thickly matted with sea-weed of a brownish or olive-brown colour as almost to present the appearance of a meadow. In the South Atlantic there is a smaller but well-defined Sargasso. Another exists in the North Pacific, between the 30th and 40th parallels, and a fourth in the Indian Ocean.

There has long been an opinion among geographers that an open sea exists in the neighbourhood of the North Pole. This was reported to Chevalier Giesecke by the natives of Greenland as far back as 1806, and since then many observations have been made which tend to strengthen the idea. Dr Kane, in his voyage to the Arctic Ocean, professed to have actually reached its shores. He and his party, having crossed a barrier of ice 80 or 100 miles in breadth, reached open water north of the parallel of 82°. As far as the eye could reach there was a sheet of water, the waves of which dashed upon the beach. The water had a temperature of 32°; water-fowl were plentiful, and seals sporting about. On the other hand, in the opinion of many, the last English Arctic expedition has dispelled the notion of an open sea. Captain (now Sir George) Nares, after advancing in the *Alert* beyond the 82d parallel, found himself on the borders of an ocean packed with ice of extraordinary character, resembling rather icebergs frozen together than ice-floes, some of it being 100 feet in thickness. This ice breaks up, however, on the return of summer, and here and there tempting channels of open water may be seen, which would probably prove fatal to a vessel, as the ice shifts about so suddenly. A small portion of this ice is drifted down Kennedy Channel and

Smith Sound; still more escapes by way of Greenland and Spitzbergen; but as the Arctic Ocean is to a great extent land-locked, a small portion only of the whole can escape before the winter again sets in. Sir George Nares is of opinion that some of the ice which he saw was at least one hundred years old, that the sea is never free from it, and that therefore an open Polar Sea is a myth. Others, however, believe that in favourable seasons the ice may all escape, and leave the way to the Pole clear.

Waves.—The tides and oceanic currents keep the waters of the ocean in ceaseless motion. The surface is also acted upon by the winds, and waves are produced. Wind-waves are caused by the friction of currents of air. If the motion of the wind be parallel to the surface of the water, there will be little or no friction, and the water will be smooth and placid; but if the wind be inclined at an angle, however slight, there will be a ripple. The friction raises a minute wave, the elevation of which protects the water behind it, and the wind consequently impinges on the surface a little beyond. As the wind continues these waves increase in number and magnitude; the agitation sinks deeper and deeper, the waves rise higher and higher, until at length the crest of the billows, impelled beyond the perpendicular, falls in wreaths of foam. The highest waves known occur during a north-west gale off the Cape of Good Hope. They do not, however, measured from the crest to the trough, exceed forty feet. When great waves reach the shore in shallow water, they increase in height, but diminish in breadth, and finally break with great violence upon the shore. Anything that diminishes the friction of the wind smooths the surface of the sea—oil, for example, or a small stream of pack-ice. When the air is moist its friction upon water is diminished. Hence the sea is not so rough in rainy as in dry weather.

CHAPTER XI.

Climate.

By the climate of any particular place we mean the general condition of the atmosphere, and the term includes not only temperature, but also the direction and force of the winds, the moisture contained in the air, and, in short, everything which affects weather. Thus the climate of a place may be warm or cold, dry or humid, equable or variable, mild or excessive. One of the chief elements in the climate of a place—we may say *the* chief—is temperature, and this is ascertained by means of a thermometer. There are two thermometers in general use in this country—that of Fahrenheit, and the centigrade thermometer. In the former, which is the one in popular use, the freezing point is 32°, and the temperature of boiling water 212°. In the centigrade thermometer the freezing point is 0°, or zero, while the boiling point is 100°.

The earth depends upon the sun for warmth as well as light. The temperature of the atmosphere is not much affected by the direct influence of the solar rays; it is chiefly warmed by contact with the earth's surface. The amount of heat which the earth receives depends upon the angle at which the solar rays strike its surface; the more nearly they approach the perpendicular the greater is the amount of heat. Hence it follows as a general rule that the countries within the tropics have a higher temperature than those nearer the poles. Old geographers were accustomed to represent the distribution of temperature upon the earth's surface by dividing it into five zones. The belt between the tropics was called the torrid zone; the districts round either pole—that is, within the Arctic and Antarctic circles respectively—were termed the frigid zones; while the broad

belts between the torrid zone and the polar circles were called temperate zones. These divisions give a good general idea of the distribution of temperature upon the globe, but when we descend to details they are found defective.

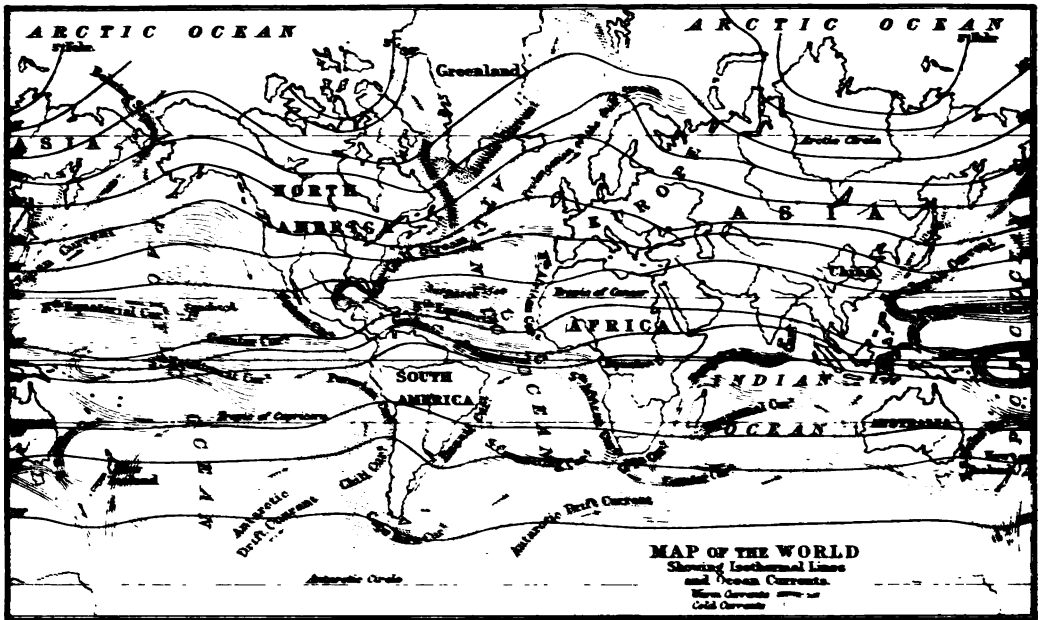
Causes which modify Climate.—Were the earth a perfect sphere entirely covered with land, and with no inequalities upon its surface, the temperature of any locality would be accurately indicated by its latitude; but practically it is found that latitude alone is far from being a certain index of the climate. The hottest tract upon the globe is a district lying between the 15th and 30th parallels of north latitude, and extending from the centre of the Sahara to the shores of the Persian Gulf. The coldest tract is said to extend along the middle and lower course of the Lena, where, in January, the average temperature is 40° below zero, or 72° below the freezing point. It is plain, therefore, that there are other causes affecting temperature besides position with respect to the equator. Some of these causes we shall briefly notice, and in doing so shall include those which affect climate generally.

1. The temperature of any country depends very largely upon the nature and elevation of the surface. We have already remarked that the atmosphere derives most of its heat, not directly from the sun, but indirectly from the earth. Now, some surfaces reflect heat more readily than others. White surfaces reflect the heat, while dark ones absorb it. Hence one reason for the great heat of the deserts of Africa and Arabia. On the other hand, forests and marsh lands absorb the sun's rays and reduce the normal temperature. It is estimated that the average annual temperature of England is two degrees warmer than it was a century ago, owing to the drainage and improvement of the land. We have already noticed the effect which elevation has upon temperature. An elevation of 300 feet makes a difference of one degree Fahr., or about the same difference that would be felt in moving one degree nearer to the pole. Thus, in ascending some of the high mountain chains within the tropics, we may, in passing from the hot plains at the

foot to the snow which rests on the summit, pass through the same gradations in temperature that we should in travelling from the equator to the poles. In South America we find flourishing towns and cities on the summit of the Andes. In India, again, sanitaria are established in the higher regions of the Himalayas and Neilgherries, and by ascending 2000 or 3000 feet Europeans can find a bracing climate to recruit their health when it has been injured by a residence in the hot plains below.

2. The presence of large bodies of water tempers extremes of climate. Water has a great capacity for heat; hence it is not raised to a given temperature so soon as land, but it retains its heat longer. Thus we find that the sea has not such a high temperature as land in summer, nor does it fall so low in winter. And those countries which, owing to a great extent of coast, are much influenced by water partake of its equable character. Hence the mild climate of the British Islands, compared with the extreme climate of countries farther from the sea. Penzance in Cornwall, and Barnaul on the Obi, in Siberia, are nearly upon the same parallel, and have both nearly the same average summer temperature. But while the difference between the mean summer and winter temperature is only about 16° at Penzance, at Barnaul it is above 55°. As evaporation is more abundant from the surface of water than from land, another consequence is that the climate of maritime countries is more humid than that of countries farther inland, and this humidity is accompanied by luxuriant verdure. It is from this cause that Ireland gains its title of the "Emerald Isle;" and if we turn to the other side of the globe, we find that New Zealand, in the centre of the aqueous hemisphere, can boast of the same bright verdure and luxuriance of vegetation.

3. The oceanic currents have a great effect upon climate. It is generally said that the west of Europe owes its comparatively high temperature to the Gulf Stream. Of late years some writers have begun to doubt whether the influence of this current is so great as is generally thought. It is true that the Gulf Stream properly so called does


ARCTIC OCEAN
ARCTIC OCEAN
Greenland
ASIA
NORTH AMERICA
EUROPE
ASIA
AFRICA
SOUTH AMERICA
INDIAN OCEAN
Tropic of Cancer
Tropic of Capricorn
Antarctic Drift Current
Antarctic Drift Current
Antarctic Circle
Arctic Circle
MAP OF THE WORLD
Showing Isothermal Lines
and Ocean Currents.
Warm Currents
Cold Currents

not exist farther north than the latitude of Newfoundland; still there is a movement of warm water from south to north far beyond this, whatever name we may give it, and this certainly has a considerable effect upon the climate of western Europe. Besides, the Gulf Stream itself, by warming the winds which sweep over it, conveys indirectly a large supply of heat to the British Islands and countries lying to the north. The coast of the United States, on the other hand, has a low temperature owing to the cold current which washes it. In the northern continents, the west coasts are much warmer than the east coasts; this is just the reverse in the southern continents of Africa and South America, and the difference is mainly due to the oceanic currents. South America is bathed on its western shore by a cold Polar Current, while its eastern coast is washed by a branch of the Equatorial Current. The east coast of Africa, again, is warmed by a branch of the Equatorial Current of the Indian Ocean; and as it must double the Cape before reaching the west coast, it has lost something of its temperature before entering the Atlantic.

4. Perhaps there is no agency so powerful in modifying climate as the prevailing winds. We find in England that very often the prevalence of easterly winds will continue the frosts of winter into the months of spring; but if the wind veers round to the west, the thermometer instantly rises, and the heat becomes almost oppressive. The reason of this has been already explained. The winds which prevail in temperate regions are generally either from the north-east or the south-west. If the former, they bring the cold of high latitudes; if the latter, they convey to us some portion of the heat of the tropics. But there is another reason why west winds should be warm winds: they, as we have seen before, are the rain-winds of temperate regions, and whenever rain falls a quantity of latent heat is set free. It is owing to this fact that the shores of Norway and the north-west coast of North America have a much higher temperature than we should at first expect.

From the foregoing remark we may see the important influence which the distribution of land and water, and

the direction of the winds and oceanic currents, have upon climate, and we can understand how a different distribution of land might materially change the general character of the climate of the globe. We might conceive the present continents so arranged that all would enjoy a warm and genial climate; or, on the other hand, were they grouped round the North and South Poles, the climate would be cold and severe. Again, we can see the immense difference in the amount of habitable surface it would make were the lofty plateaus and mountain chains of low latitudes transferred to the frigid zones. These may appear useless speculations, but it is quite possible that in past geological ages some such changes as we have glanced at may have taken place; and, at any rate, we learn how intimate are the relations between one part of the natural world and another, and that the various operations of nature are not the result of blind chance.

Isothermal Lines. — The influence of the various modifying causes upon the normal temperature of the globe is clearly illustrated by isothermal lines, or lines of equal average temperature. These lines are drawn through places which have the same mean annual temperature, and it will be seen that, in high latitudes especially, they diverge very much from the parallels. It should be borne in mind that these lines are drawn on a map as if all the points through which they passed were at the level of the sea; and therefore the temperature of higher regions must be reduced by subtracting one degree for every 300 feet of elevation.

Commencing with the tropics, we notice two isotherms, north and south of the equator respectively, which denote a mean annual temperature of 80°. The two lines make a continuous curve, which may be said to start from Quito. It then runs northward through Guatemala and Belize, proceeds through the West India Islands, and across the Atlantic to Sierra Leone. It then takes a great sweep northward, passes through the district of greatest heat, rises again as it crosses the Plain of Hindostan, and then bends south in crossing Further India. It then proceeds

half way across the Pacific, at a distance of about 10° north of the equator, and then returns at an equal distance south of the line. It touches the northern part of Australia, and then crosses the Indian Ocean to Zanzibar. It now makes a sudden bend southward, and then, turning again to the north, leaves the continent near the equator, and, crossing the Atlantic again, passes through Maranhao to Quito again. Now, all countries enclosed by this curve have an average annual temperature of at least 80°, and the main fact which strikes us is that within the tropics the presence of large masses of land increases the heat.

It will not be necessary to notice all the isotherms which may be seen on a map, but one or two are instructive. The isotherm of 60° in the southern hemisphere may be easily remembered, as it passes through, or very near, Buenos Ayres, Cape Town, and Melbourne. In the northern hemisphere its direction is indicated by the following places:—San Francisco, Cape Hatteras, Madrid, Rome, Constantinople, and Shanghai. The isotherm of 50° in the northern hemisphere is an important one. It begins in the Pacific about the parallel of 45°, rises as it approaches the continent of America, passes through Vancouver Island, and then, turning south-east, reaches New York. The influence of the Gulf Stream and the south-west winds now carry the line almost to the north of Ireland. It then turns slightly to the south-east, passing through Dublin, London, and Vienna, and is continued through the Crimea into Asia, which it crosses almost in a straight line.

The points established by the isothermal line of 50° are these:—That in these latitudes the sea is much warmer than the land; that the west coasts are warmer than the east coasts; and that the Atlantic, in similar latitudes, has a higher temperature than the Pacific. These facts are still further illustrated by the isotherm of 40° in the northern hemisphere. It commences on the west coast of North America about the parallel of 60°, and gradually bends southward, passing through Lake Superior and the town of Quebec. On entering the Atlantic the influence of

the northward flow of warm water in that ocean is at once apparent. From the neighbourhood of St John's, in Newfoundland, the isotherm proceeds northward through Iceland into the Arctic Ocean. It then again bends south, passes through Drontheim and Moscow, and, crossing the Ural River, proceeds in a straight line across the continent of Asia. It touches the Amoor at the junction of the Songari, bisects the island of Saghalien, and turns northward, following the course of the warm current which washes the eastern shores of Japan.

But places may have the same mean annual temperature and yet differ very much in the character of their climate. Take London and Vienna, for example. The mean winter temperature of the former is 37°, its mean summer temperature 64°; Vienna, on the other hand, has a mean winter temperature of 29°, while the summer average is 70°. It is important that the extremes of heat and cold should be noticed; for while some plants, like the myrtle, cannot endure severe winters, others, like the vine, may live through a severe winter, but require a great summer heat to bring their fruit to perfection. Hence, besides the isotherms, other lines have been constructed which show the average summer and winter temperatures respectively: the former are termed isotheres, or *isotheral lines;* the latter isocheimenes, or *isocheimal lines.*

Taking the months of January and July as, respectively, the coldest and warmest months in the northern hemisphere, and the warmest and coldest months of the southern hemisphere, a series of observations has been taken in order to determine the annual range of the thermometer in various parts of the world. It is found that within the tropics the range is very small—in other words, the difference between the hottest and the coldest month in the year is slight. As we recede from the tropics, however, the difference increases rapidly. In London, as we have seen, this difference is 27°, and in no part of England does it exceed 30°; at Vienna it is 40°, and at Yakutsk 106°: this is the greatest range known. No part of the open ocean, in any part of the world, has a range of more

than 40°, and only in North America and Asia does it reach 60°. The highest observed range in the southern hemisphere is Patagonia, where it is 40°. It is a remarkable fact that the extremes of heat upon the earth's surface differ much less than the extremes of cold. Thus the mean summer temperature of Yakutsk is equal to that of Great Britain; it is the excessive cold of winter which reduces its mean annual temperature to 13°. This uniformity of summer heat is not difficult of explanation. Within the tropics the days and nights are pretty equal in length all the year round; but as we recede from the tropics the days in summer lengthen considerably, so that within the Arctic circle the sun never sets for weeks together. The heat thus accumulates, and a considerable temperature is reached during the brief hot summer even in the Polar regions. Of course, the very same cause operates in producing excessive cold in winter.

Climates are sometimes classified according to the annual range of the thermometer. Thus in insular and tropical climates the variation does not exceed 30°. In continental climates the range is from 30° to 60°. Where the variation exceeds 60° the climate is said to be excessive.

From observations which have been made, it appears that the temperature of the whole globe goes on increasing from January to July to the extent of 8°, and that the mean temperature of the northern hemisphere is 60°, while the mean temperature of the southern hemisphere is only 56°. The explanation of this fact probably is, that there is more rain in the northern hemisphere and less evaporation, and we know that temperature is lowered by evaporation and increased by precipitation. Something also may be due to the melting of icebergs, which are very numerous in the Southern Ocean, owing to the great expanse of water, which allows them a free passage from the Antarctic Ocean.

Weather is the condition of the climate of any particular locality at some particular time; hence climate may be looked upon as the general average of the weather. Weather is proverbially uncertain, but by careful observa-

tion its changes may often be foreseen and provided against. It is well known that among the signs of rain is an unusual clearness in the air: this is caused by an excess of moisture in the atmosphere. Another sign of rain is a falling barometer. It was thought at one time that a low barometer was also caused by an excess of moisture in the air, since aqueous vapour is lighter than its own volume of dry air. But experiments have proved that moist air is heavier than dry air of the same temperature. The barometer falls with a south-west wind because, in spite of the moisture it brings, it is still lighter than an east wind, owing to its higher temperature. Another sign of rain is what sailors call "backing"—that is, when the wind shifts round from the east to the north and then to the west. We have already explained that this is the way the wind veers in a cyclone, whereas in an anticyclone, which brings with it settled weather, the wind moves in the same direction as the hands of a watch (p. 78). We have also mentioned, in a previous chapter, that in the neighbourhood of cyclones the air is rarefied by the rotation of the storm. Now, as all storms are more or less cyclonic in character, it has become an established rule that a sudden fall of the barometer shows the approach of a storm; a gradual fall foretells rain.

The electric telegraph is now of great service to those who make the changes in the weather their special study. Meteorological stations are established in various parts of the British Islands and on the Continent; and from the reports sent in to the Central Office in London it is possible to trace the movements of areas of high and low pressure, and thus the general character of the weather may be predicted with considerable certainty twenty-four hours beforehand. By means of the Atlantic cable, also, we are sometimes informed of the approach of a storm several days before it arrives.

CHAPTER XII.

PLANTS AND ANIMALS.

Plants.—In the previous chapters we have treated of inorganic matter; we have now to consider the phenomena connected with life. Animals derive their food mainly from vegetation: vegetation derives its support directly from inorganic substances. Plants obtain their food from the earth and from the atmosphere. From the former they receive hydrogen and nitrogen in the form of water and ammonia; from the latter, carbon and oxygen in the form of carbonic acid. Having imbibed these substances they give back the oxygen to the air, and consolidate the carbon, water, and nitrogen into wood, leaves, flower, and fruit. Though the quantity of carbonic acid in the atmosphere is exceedingly small when compared with its other constituents, yet it is amply sufficient to supply the whole vegetable world, and is constantly being supplied by the breath of animals, by combustion, fermentation, the decomposition of vegetable matter, and by volcanoes. A certain amount of more solid food—such as the alkalis, phosphates, silicates, and sulphates—are required for the growth and perfection of plants. It is to supply this that manures are required for exhausted soils. Cereals and grasses require silica, which gives the stiffness to straw and to canes. The family of the Cruciferæ, which includes cabbages and turnips, requires a certain amount of sulphur.

Plants require rest as well as food. In northern and temperate latitudes most plants rest during winter: within the tropics the dry season is the time for rest. It is well known, also, that many flowers close their leaves towards evening, and wake with the dawn. Some plants, how-

ever, seem to keep awake during the night, and then only give out their choicest perfume. Many of the jessamines are most fragrant during twilight, while other plants reserve their sweetness for midnight. Light and heat seem essential to the germination and growth of plants, but the quantity necessary to some plants must be very small, since vegetable life is almost universally diffused. In the Arctic regions no land has yet been discovered which is entirely destitute of vegetation. The *Palmella nivalis*, or red snow of the Arctic regions, finds nourishment in the snow itself; it has also been met with on the Alps and Pyrenees. On the other hand, a species of Conferva flourishes in the geysers of Iceland, where the water is almost hot enough to boil an egg. In the ocean the existence of vegetable life is limited by the depth to which sunlight can penetrate.

Plants are divided into two great classes: flowering and flowerless. The latter, called *Cryptogams*, include ferns, mosses, lichens, fungi, and sea-weeds. The former are subdivided into *monocotyledons*, which spring from one seed-lobe or cotyledon, like a grain of corn; and *dicotyledons*, which spring from two seed-lobes, like those of a pea or bean. In monocotyledons the young plant commences with one little leaf wound spirally outside the seed. As the plant grows new leaves shoot up, and the outer case of dead leaves left behind forms the outside of the stem. These plants, therefore, grow from within, and their leaves have parallel veins. To this class belong the cereals, grasses, lilies, and palm-trees. In dicotyledons the double seed gives off two leaves, diverging as they rise, and allowing a stem to come up between them. The leaves have netted veins, and the stems distinct bark. In shrubs and trees belonging to this class the trunk increases by successive rings, which mark the years of its existence. All British trees and woody plants belong to this class.

The total number of species of plants known to exist has been estimated at 120,000; and of those actually described it is said that the *acotyledons*, or cryptogams, amount to 15,000; monocotyledons to 14,000; and dicoty-

ledons to 76,000. But these classes are distributed very unequally upon the earth's surface. Within the tropics the proportion of dicotyledons to monocotyledons is four to one; in temperate regions, six to one; in the polar regions, two to one.

Vegetable Zones.—Since plants depend so much upon heat, light, and moisture, there must be an intimate connexion between them and climate. And just as the surface of the globe has been divided into zones of climate, so it may be divided into zones of vegetation, which, though not rigorously exact, give a good general idea of the distribution of plants. Thus we find that the

Region of	*Corresponds to the*
Palms and Bananas	Equatorial Zone.
Tree-ferns and Figs	Tropical Zone.
Myrtles and Laurels	Sub-Tropical Zone.
Evergreen trees	Warm Temperate Zone.
Deciduous trees	Cold Temperate Zone.
Pines	Sub-Arctic Zone.
Rhododendrons	Arctic Zone.
Alpine plants	Polar Zone.

And as, in passing from the base of a mountain within the tropics to the region of eternal snow, we pass through the various climates which exist on the surface between the equator and the poles, so we meet with different aspects of vegetation corresponding to these different zones.

It should be borne in mind, however, that though the tops of mountains in southern Europe, and even within the tropics, may have the same average temperature as places within the Arctic circle, yet there is one very important difference. In high latitudes the cold is owing to the absence of the sun during a great portion of the year, and to the obliquity of his rays when present; on the top of the Alpine chain it is owing to elevation. The direct rays of the sun are much fiercer on the Alps than in Spitzbergen. Hence it follows that, although we may find certain plants common to the Alps and the Arctic regions, they will be much larger in the former locality. These remarks apply with still greater force to the mountains within the tropics. Rhododendrons are common to

the north of Europe, the Alps, and the Himalayas. In the first locality they appear as low, stunted shrubs; in the Alps, as bushes; while in the Himalayas they are magnificent trees. The more abundant the rays of the sun, the greater is the amount of vitality in organic life.

Botanical Centres.—The laws which relate both to the vertical and the horizontal distribution of vegetation are subject to local modifications which are sometimes difficult to explain. Thus some plants seem naturally limited to certain districts, yet, when removed to other regions, they thrive equally well. Viewing the subject in this light, botanists have divided the land surface of the globe into about twenty-five *phyto-geographic* regions, or botanical centres, each distinguished by one or more natural family of plants. It would be tedious to enumerate all the regions that have been thus mapped out, but some of the more remarkable ones may be glanced at.

1. The shores of the Mediterranean is the region of the *Labiatæ* and *Caryophyllæ*. To the Labiate tribe belong mint, thyme, rosemary, lavender, and many others, all remarkable for aromatic properties; to the Caryophyllæ belong the pink, catchfly, and sandwort. This region is also distinguished by the number of evergreen trees, such as the evergreen oak, the arbutus, the myrtle, jessamine, and cypress. It is interesting to notice that the plants which characterize the Mediterranean region at the present day are such as flourished in England during the Miocene period.

2. In Africa, south of the tropic of Capricorn, we have the region of *Stapelias* and *Mesembryanthema*, or fig-marigolds. This region is distinguished by plants having thick, fleshy leaves, but bright and beautiful flowers. Here are found aloes, geraniums, and irises, but, above all, heaths. Of these last there are about 400 species, all exceedingly beautiful. There are also in this region 133 species of the house-leek tribe.

3. Eastern Asia, from the parallel of 30° northward to the Amoor, including the Japan Islands, is the region of the *tea-plant*. Here flourish the camellia, the *thea*, or tea-

plant, which is a species of camellia, the citron, and the brilliant azalea.

4. The southern part of the United States may be called the region of Magnolias. Its trees have broad shining leaves and beautiful flowers. Here flourish the tall tulip-tree, the long-leaved pitch pine, the deciduous cypress, the aquatic oak, and the swamp hickory.

5. In South America, between the parallels of 5° and 20° south, and at an elevation of from 5000 to 9000 feet, is the region of the *Cinchonæ* or Peruvian bark.

6. New Zealand forms another region distinguished by its graceful ferns and valuable pines. Out of 2000 native plants only 730 have flowers, and of these two-thirds are peculiar to the islands.

7. Lastly, in South Australia we find the region of *Epacridæ* and *Eucalypti*. Here the trees are all evergreen, with grass-like and stunted foliage; here flourish the myrtle, acacia, and gum-tree, with arborescent ferns and nettles of gigantic size. The vegetation of this portion of Australia resembles that which flourished in England during the Oolitic period.

Marine Vegetation.—Marine plants consist of two groups: a jointed kind, which includes the *Confervæ*, or plants having a thread-like form; and a jointless kind, such as the weeds used in making kelp, iodine, and glue. As the various depths of the ocean differ from each other in pressure and in the amount of light and heat they receive, so do they in the character of marine vegetation; so that there is a horizontal and vertical distribution, just as among terrestrial plants. Marine vegetation differs from that of the land in this respect, that, so far as is known, it is more abundant in temperate regions than within the tropics. One or two species bear flowers, but the most are cryptogams. Some plants are remarkable for their size and the extent of their range. The *Macrocystis pyrifera* exists in vast detached masses, like green meadows, in every latitude from the Antarctic Ocean to the parallel of 45° north; and individual plants sometimes attain a length of 700

feet. Sea-weeds derive all their nourishment from the water, hence it is not necessary that they should have roots. Many species attach themselves to stones, but others are provided with air-bubbles to float them, and exist permanently on the surface. This is the case with those which form the various *Sargasso Seas*.

There is a species of marine vegetation which is so minute as to be scarcely visible to the naked eye. Where very abundant it gives a pale-brown appearance to the surface of the sea. When examined by the microscope, the plants are found to consist of small groups of cells, which multiply with great rapidity. They increase in numbers with the latitude up to the farthest point reached by man. These *diatomaceæ*, as they are called, are met with everywhere, from Victoria Land to Spitzbergen; and so abundant are they in the Antarctic Ocean that they form—as we have previously stated—a deposit of the silica which they have extracted from the sea water. A similar deposit has been found in the North Atlantic between Greenland and Labrador.

Animals.—Animals depend in a great measure upon plants for food, and, like them, are affected by varieties of climate. Thus the development of animal as well as vegetable life increases in energy and variety from the poles to the tropics. It has been noticed, also, that animal life decreases in abundance as we recede from the coast and penetrate the interior of continents. Where the climate is less humid vegetation will be less abundant, and there is thus less support for animal life. But though the interior may be less prolific in the number of species, the individual forms are generally better developed. For it has been found that, while a moist and warm climate is best adapted to vegetation, a hot and dry climate brings animal life to greatest perfection. Thus the New World is distinguished for the luxuriance and leafiness of its vegetation, but is far inferior to the Old World in the size and beauty of its animals.

There is among animals, as among plants, a vertical as well as a horizontal distribution. The chamois is confined

to the higher regions of the Alps; the llama and alpaca, in a natural state, are found only on the summits of the Andes. We notice also the same evidence of certain local centres as was observed with respect to plants. Nor can we explain this fact by supposing that the soil and climate of one region are unsuited to the animals indigenous to another. On the contrary, the animals of one region, when introduced by man into another with a similar climate, are often found to multiply with extraordinary rapidity. The pampas of South America swarm with wild cattle and horses, descended from breeds introduced from Europe; and oxen and sheep introduced into Australia have become vast flocks and herds. One of the most remarkable examples of the limitation of a species to a particular district is afforded by the tse-tse fly of South Africa. The bite of this insect is fatal to the horse, ox, and sheep: fortunately, the infested area is limited. Sometimes the boundary is a river, in other cases there is no natural boundary, yet the limit is so well defined that for a horse to cross a well-known line is death.

What prevents the fly from migrating from one district to another we cannot say. That animals as well as plants do migrate is well known. Among the quadrupeds of Europe there is no family peculiar to the Continent. Most of them were derived probably from Asia. All the quadrupeds indigenous to Great Britain, together with the hyæna, tiger, bear, and wolf, whose bones have been found in caverns in this country, seem to have migrated from Germany. Ireland was probably separated from Britain before all the animals reached it: hence the absence in that island of the squirrel, mole, dormouse, and several other small quadrupeds.

The present races of plants and animals are the descendants of those which flourished in geologic ages, and whose remains we now find in a fossil state, so that we must look to geology for an explanation of the present distribution of organic life. Throughout the vast periods which preceded the advent of man, we find that the climate and

other external conditions of the earth were undergoing gradual changes, and that vegetation and animals underwent corresponding changes. Whether there were successive creations, or whether plants and animals were enabled to adapt themselves gradually to the changes that took place, and so to pass into new species, is a question rather for the naturalist than the geographer. It is sufficient for our purpose to know that a real distribution both of plants and animals had taken place before the close of the Tertiary period, and hence we account for certain well-defined *habitats* which we now observe. In Australia and South America the existing races bear a close analogy to the extinct races, the fossils, however, being generally much larger. In Europe and Asia, on the other hand, the difference between the existing and extinct races is very marked. This arises mainly from the fact that many large animals have become extinct in the old continent since the close of the Tertiaries. From the evidence afforded by flint implements found in drift deposits, it would appear that the Irish elk, the mammoth, and the hairy rhinoceros were at one time co-existent with man.

On taking a general survey of the distribution of animals, we are struck with the fact that each of the continents seems to have its characteristic fauna. Thus Africa is remarkable for its huge pachyderms; tropical Asia for its carnivora; South America for its edentata; and Australia for its marsupialia. Mr Wallace divides the whole globe into six regions, each of which contains four sub-regions. Under the term *Palæarctic* he includes the whole of Europe, Africa north of the Sahara, and the greater part of Asia. He supposes this region to have been the original birthplace or cradle of all the animals now existing, and that from this region they migrated to different parts of the world. The *Ethiopian region* consists of Africa south of the Sahara, and includes Madagascar. The hippopotamus and the giraffe are peculiar to this region; and it is characterized also by its antelopes, anthropoid apes, and lemurs. The civet family is also

numerous; but there is a remarkable absence of bears and deer. The *Oriental region* comprises all tropical Asia east of the Indus, together with Java, Borneo, and the Philippine Islands. This region is remarkably rich in birds and insects: the pheasants especially form a striking group.

Turning now to the New World, we meet first with the *Nearctic region*, which embraces almost the whole of North America. Here the fauna bears a certain resemblance to that of the Palæarctic region, but is not identical. Among the animals peculiar to this region are the musk-ox, the pronghorn, and the prairie dog. The *Neotropical region* comprises all South America and the tropical part of the northern continent. Here we find a great variety of the lower types of animals, with a corresponding scarcity of such higher forms as characterize the tropical regions of the Old World. The great bovine family, for example, is entirely unknown among the indigenous animals of South America. Among those peculiar to this region may be mentioned the tapir, peccary, sloth, armadillo, llama, chinchilla, and the vampire-bat. Among birds may be mentioned the toucan and humming bird. Lastly, we have the *Australian region*, which includes also New Guinea and the islands extending thence in a south-easterly direction to New Zealand. This region is separated from that of Eastern Asia by a deep channel which runs between the islands of Bali and Lambok, and between Borneo and the Celebes.

The Australian region is remarkable for its marsupials, and for a still lower type, the monotremes, which include that strange animal the *ornithorhynchus*. But there is an almost entire absence of at least five orders: quadrumana, pachydermata, ruminantia, carnivora, and insectivora. About fifteen families of birds are peculiar to this region, among which are the birds of paradise, the honeysuckers, the lyre-birds, the lories, the mound-makers, and the cassowaries. We have already pointed out the resemblance there is between the existing flora of Australia and that which flourished in England during the Oolitic period.

The same resemblance may be traced in the fauna, and it is explained by supposing that the Australian continent was connected with Asia in early geologic times, but that all migrations from one to the other have been interrupted since the Oolitic period.

Acclimatization of Plants and Animals.—From the earliest times man has selected certain plants and animals for his own use, and by a careful cultivation has almost changed them into new species. The olive, vine, and fig-tree have been cultivated from time immemorial. Wheat, rice, barley, and maize are but the seeds of certain grasses. Our apples and plums are of the same species as the crab and sloe. Nor is the change less in domestic animals. The numberless variety of pigeons, differing from each other in form and plumage, all spring from the rock pigeon. The dog, which shows a still greater variety of form, is probably descended from the wolf, the fox, and the jackal. Almost all our useful animals were in very early times domesticated in Asia. The other continents have contributed little in this way.

When new lands are discovered and colonized, man takes with him the plants and animals which he finds useful or necessary, and occasionally brings back others to the mother country. On the discovery of America it was found that the New World was almost destitute of useful animals, and accordingly the domestic animals of Europe were introduced, along with the sugar-cane, the coffee and cotton plants, and the cereals. In return, America gave to the Old World the potato, the cocoa plant, the vanilla, and the tobacco plant. More recently the cinchona has been transplanted to the uplands of India, and the llama and alpaca have been introduced into Australia. This continent, indeed, owes more than America itself to the process of acclimatization. Salmon have been introduced into its rivers, song-birds into its woods, and sheep into its extensive pastures.

OUTLINES OF PHYSIOGRAPHY.

PART II.

OUTLINES OF PHYSIOGRAPHY.

PART II.

CHAPTER I.

Refraction of Light—Telescopes.

When a ray of light falls upon any substance, part of it passes through, another part is reflected, while the remainder is dispersed and lost. The portion of light which is reflected follows a simple law: The angle of incidence is equal to the angle of reflection,—that is, the ray is reflected from a surface at the same angle as it strikes upon it. A knowledge of this law is sometimes made use of in finding the heights of objects. Thus, suppose it is required to find the height of a tower. Place a mirror upon the ground, and, looking at the mirror, walk backward until the top of the tower is seen reflected in the glass; then, from a knowledge of similar triangles, we get the following proportion:—As the distance of the foot from the mirror is to the height of the eye above the ground, so is the distance of the mirror from the base of the tower to the height of the tower.

Refraction.—When a ray of light passes obliquely from one medium into another of different density it is more or less refracted. We have already referred to the effect of refraction upon the apparent position of the sun and other heavenly bodies when not in the zenith. We now pro-

ceed to explain the amount of refraction more precisely. Let A B be a surface of water, and C D a perpendicular to it. From the centre O describe the circle A B C D. If a

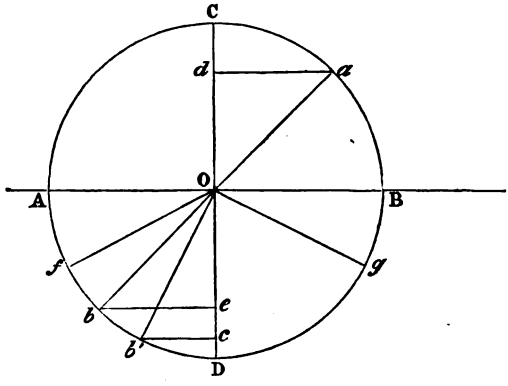


FIG. 1

ray of light coming from *a* enter the water at O, it will not proceed in a straight line to *b*, but will be bent *towards* the perpendicular and reach *b'*. In a similar manner, a ray proceeding from *b'* will, on emerging from the water, be bent *from* the perpendicular and reach *a*. Thus a ray of light in passing from a rare into a denser medium is bent towards the perpendicular, and in passing from a dense into a rarer medium is bent from the perpendicular.

We can see now why it is that a stick, when placed in the water, appears to be broken. An object always appears to lie in the direction from which the rays proceeding from it reach the eye; and the rays which come from that part of the stick which is in the water do not, owing to refraction, come to the eye in a straight line. The effect of refraction may also be illustrated by a simple experiment. Place a silver coin in an empty basin, and then step backward until the coin is just visible over the rim of the basin. A step farther back renders the coin invisible. If now some one pour water carefully into the basin, so as not to

disturb the coin, it will again become visible. The reason may be seen on referring to our figure. If A D B be looked upon as the basin, then, when it is empty, a coin placed at *b* would be visible to a spectator at *a*, but if the coin be placed at *b′* it would not be visible. When the basin, however, is full of water, a ray of light proceeding from *b′* is refracted on emerging from the water at O, and becomes visible at *a*.

From *a* and *b′* let fall perpendiculars to *d* and *c*; then the lines *a d* and *b′ c* represent the relation between the angle of incidence and the angle of refraction. In the case of water the proportion which *b′ c* bears to *a d* is about three to four, or, more precisely, 1 to 1·33; and whatever may be the angle of incidence, except, of course, when the ray falls at right angles, the proportion is always the same. The law is thus expressed: The ratio between the sines of incident and refracted rays is always the same for the same substance. The words "for the same substance" are important, for all substances have not what is termed the same *index of refraction*. In the case of water we find that the proportion of *a d* to *b′ c* is about four to three; in other substances it is much greater. Thus the index of refraction for—

Water is, . . .	1·3
Crown glass, . .	1·5
Flint glass, . .	2·0
Diamond, . . .	2·7

Referring once more to Fig. 1, it will be seen that if a point *b* be taken, so that *b e* bears to O B the proportion of three to four, then a ray of light proceeding from *b* to O would emerge at B parallel to the surface of the water. This is called "the critical angle," because if the ray proceeds from any point between *b* and A, from *f*, for example, it will not emerge from the water at all, but will be reflected back in the direction of *g*. This is an example of what is called *total reflection*, the surface acting as a perfect mirror. It is upon this principle in optics that the mirage depends.

The **Mirage.**—There appear to be three different forms

of this curious phenomenon. In its simplest form the ground has the appearance of a tranquil lake, on which are reflected trees and rocks, or neighbouring villages. This kind of mirage is very common in Upper Egypt and other parts of Northern Africa. The explanation is this: the air in contact with the heated soil of the desert being greatly expanded, the lowest layers are less dense than those above them. A ray of light in passing from an elevated object, such as the top of a tree, is refracted more and more as it proceeds, until it reaches a stratum of less density than those above it. If now the angle of incidence be greater than "the critical angle," the ray will not pass into the rarer medium, but total reflection will take place, the angle of reflection being equal to the angle of incidence. The stratum of air acts as a mirror, and the objects reflected in it present the same appearance as if reflected from still water. Another kind of mirage is due to horizontal reflection. Dover Castle has sometimes been seen complete from Ramsgate, although there is a hill between the two places which, under ordinary circumstances, hides a portion of it. In this case there are evidently vertical columns of air of different densities which bring about total reflection horizontally. There is also a kind of inverted mirage called *looming*, which is often visible at sea in high latitudes. In this case the images of distant objects, such as ships, are seen in the air, in an inverted position. In all cases the appearance is caused by the reflection of rays proceeding from real objects. This reflection arises from unequal densities in adjacent strata of atmosphere, which may be produced either by heat or the presence of aqueous vapour.

Colour.—The light which we receive from the sun is white: but this white light is made up of seven primary colours. This fact was discovered by Newton. If a beam of solar light be admitted through a small opening into a dark room, and allowed to fall on a white screen, it produces a round white spot. If now a prism be interposed, edge downwards, the beam will be refracted upwards—that is towards the perpendicular on entering the prism,

and from the perpendicular in emerging from it—and at the same time the white light will be resolved into its component colours. The result is a rainbow-coloured band, termed a *spectrum*. Beginning at the top, and coming downwards, the colours occur in the following order: violet, indigo, blue, green, yellow, orange, red. The explanation is, that the simple colours which make up white light possess different degrees of refrangibility: the red undergoes the least change, the violet the most. The prism, as it were, draws asunder the various constituent rays which make up the beam of light. If a small opening be made in the screen, so as to allow rays of only one colour to pass, it will be found, on transmitting these through a second prism, that no further dispersion is effected; hence these are termed primary colours.

Natural bodies possess the power of absorbing and selecting certain portions of the white light, and thus produce colour. When the light which falls upon a body is wholly absorbed, the object is black; if all the coloured rays are absorbed equally, but only partially, the result is a grey colour; if none of the rays are absorbed, the object is white. Bodies of all colours reflect white light from their surfaces; their distinctive colours depend upon the light which has plunged to a certain depth within the object. There it is sifted: certain portions are absorbed, the remainder is then discharged, and gives the object its colour. The colour of the sky is probably due to the aqueous vapour in the atmosphere, which absorbs all the colours of the sun's light except the blue.

The **Rainbow**.—This phenomenon is only seen when rain, or something analogous to it, is falling, and the spectator is standing with his back to the sun. It is caused by the decomposition of the light when it passes into the rain-drops, and by its reflection from the inside face of each drop. A beam of solar light falling obliquely on the surface of the rain-drop is refracted on entering it; part passes through, but another portion is reflected at the back of the drop, and on emerging from it again is, of course, again refracted. Thus the portion of light which

ultimately reaches the eye of the spectator has been twice refracted and once reflected. Each rain-drop, therefore, acts like a small prism, and decomposes the white light into its primitive colours. Let A B C (1) and (7) repre-

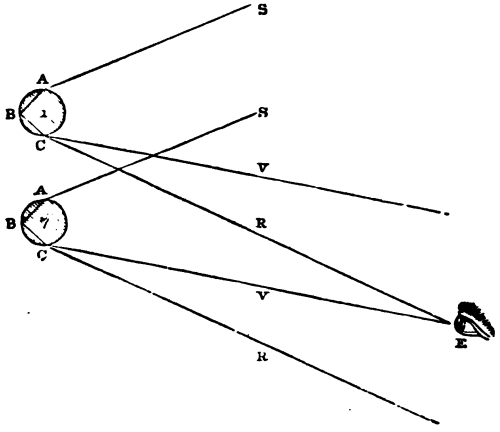


FIG. 2.

sent two drops of rain, and S A parallel rays of sunlight falling upon them. These rays are first refracted to B, and thence reflected to C, where they leave the drop decomposed into their constituent colours. The violet rays, being the most refrangible, take the highest course, C V, and the red, being least so, the lowest, C R; the other rays being found in the intermediate space. The original rays being parallel, those formed by their decomposition are also parallel. Now, the eye at E will only receive the red rays from the upper drop (1), all the others passing above it; and only the violet rays from the lower drop (7), the remainder falling below it, whilst the intermediate colours will be received from drops placed between. Hence the various colours will be seen arranged in this order in the sky, and forming a portion of a circle or bow round the spectator.

The rainbow is in reality a portion of the base of a cone, the apex of which is the eye of the spectator, and the axis the continuation of a line from the sun through the observer's eye. About one-half of the circle forming the circumference of the base of this cone is generally seen, but if the observer be on a mountain top, a still larger arc is visible. It will be seen from what has been said that no two persons see the same rainbow at the same time, as no two can simultaneously occupy exactly the same position. Sometimes a second but fainter bow is seen outside the first one. In this case the colours are less distinct, and their order is reversed, the violet being on the outside. The second bow is produced by rays which have undergone two reflections within the drop, as seen in the accompanying

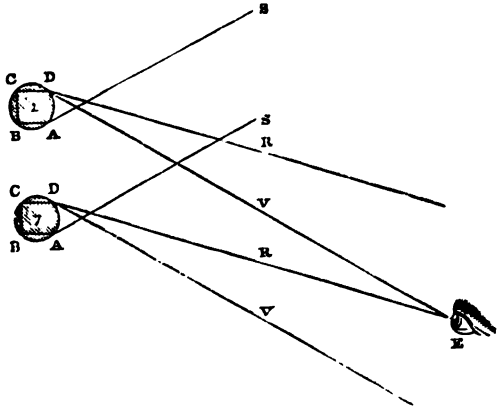


FIG. 3.

figure. It is the double internal reflection that weakens the colours and reverses the order in which they come.

Rainbows are sometimes seen in waterfalls, and even in fountains. On a bright summer's morning every dew-drop presents a rainbow in miniature. The coloured circles called fog-images which are occasionally seen to

surround the shadows of objects when thrown on an opposite bank of mist, and the halos which are sometimes seen round the sun and moon, are all of the same nature as the rainbow.

Lenses.—A convex lens may be looked upon as two prisms with their bases placed together; and hence, when parallel rays fall upon it, they converge to one point. Let A B (Fig. 4) be the section of such a lens, upon which a number of parallel rays are supposed to fall. It will be seen

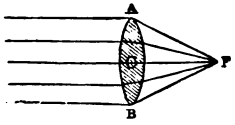


FIG. 4.

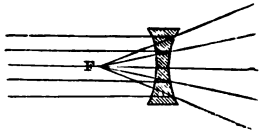


FIG. 5.

that all the rays except the middle one fall obliquely upon the surface. The centre one will pass straight on in the direction C F, but the rest will be refracted and meet in F: this point is called the focus. If the incident rays, instead of being parallel, converge before falling upon the surface, the focus will be nearer the lens; if they diverge before being refracted, the focus will be farther distant. Rays diverging from the point F and falling upon the lens would emerge on the other side in parallel lines.

The action of a concave lens (Fig. 5) is just the reverse. If parallel rays fall upon it they will diverge after passing through, and would never meet. But if the divergent rays be traced back to the point where they would meet if produced on the other side of the lens, we find what is called the virtual or imaginary focus, F. It will be seen, also, from an examination of the figure, that if parallel rays falling upon a concave mirror emerge as divergent rays, then rays converging at the same angles, and falling upon a concave mirror, would emerge in parallel lines.

Where the rays meet after passing through a convex lens, they form an inverted image of the object from which

they proceed. This is illustrated by Fig. 6, where the rays from the points A and B are shown, after passing through the lens C D, to be again united in the points A′ and B′, corresponding to its opposite focus. This fact

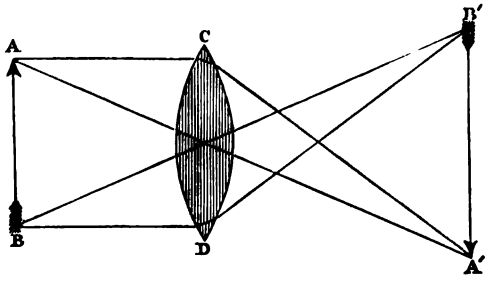


FIG. 6.

may also be easily proved by experiment. Hold a convex lens at a distance from the window, and place behind it a sheet of paper exactly in the focus. It will be found that a distinct image of the window and the objects beyond it will be formed on the paper, but the picture will be inverted.

The front portion of the human eye, including the cornea and the crystalline lens, is a convex lens of considerable power; and where there is perfect vision, the rays which enter the pupil form an image on the *retina*, as the network of nerves at the back of the eye is called. In old age the eye has a tendency to become less convex, and thus the images of near objects are formed behind the retina, and the vision is indistinct; hence convex glasses are used to assist the sight of old people. In short-sighted persons the lens of the eye is too convex, and the image is formed before reaching the retina; they therefore require concave glasses to throw the image farther back. Old people can see objects at a distance, because the rays from distant objects are more parallel than those which are near; short-sighted persons, on the other hand, can see near objects best, because, the rays being more divergent, the

excessive convexity of the eye is not felt. The eye can accommodate itself, within certain limits, to the various distances of objects by altering the convexity of the crystalline lens; but when the eye is too flat or too convex, the alteration in the crystalline lens is insufficient.

Telescopes.—Who invented spectacles is not known, but they came into use about the middle of the thirteenth century, and early in the seventeenth century they led the way to the invention of telescopes. These were at first merely toys, but Galileo turned the invention to a practical use. The telescope which he invented was made on the same principle as an opera-glass. The object-glass was a convex lens, and the eye-glass concave. In Fig. 7, let *a b* represent an arrow, from every point of which a cone of

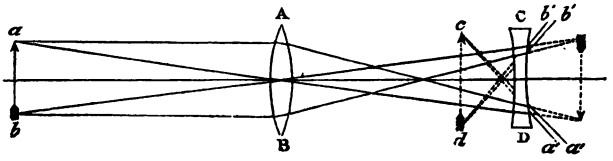


FIG. 7.

rays will fall upon the object-glass, A B. Let the two lines drawn from *a* and *b* respectively represent two rays, one of which is parallel, and the other passing through the centre. As the object-glass is a convex lens, the lines proceeding from *a* and *b* respectively become refracted, and would ultimately meet in the focus and form an inverted image. If, however, a concave lens, C D, be interposed before the rays reach the focus, the converging rays will be rendered nearly parallel, as in *a′a′ b′b′*, and present a distinct image to the eye. Now, as an object is seen in the direction in which the rays from it enter the eye, we see a distinct image of the arrow at *c d*.

The objection to this form of telescope is that, owing to the dispersive action of the concave lens, many of the rays pass outside the pupil of the eye, and consequently the field of view is small. To remedy this Kepler employed

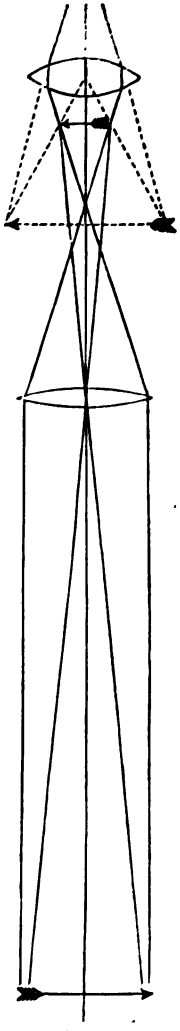


FIG. 8.

two convex lenses, but in this case the focus comes between the eye-glass and the object-glass (Fig. 8). The object-glass converges the rays as before, and forms an inverted image at the focus. The eye-glass, or ocular, as it is sometimes called, converges the rays proceeding from the inverted image, and renders them parallel; and, as in the former case, the object is seen under a large visual angle. Kepler's instrument is called the *astronomical telescope.* It has a much larger field of view than Galileo's, but everything is inverted. This is a matter of little consequence in astronomical observations, and in telescopes constructed for ordinary use the inverted image is corrected by inserting other convex lenses between the object-glass and the ocular.

As a lens is in reality a combination of prisms, it follows that the light which is refracted is also coloured to a certain extent. This *chromatic aberration,* as it is termed, is got rid of by using two lenses of different shapes and made of different kinds of glass. Different media have not only different refractive powers, but also different dispersive powers—that is, they spread out the spectrum to a greater or less extent. The dispersive power of flint glass is double that of crown glass, while its refractive power is nearly the same. Now, if the object-glass be made of crown glass, chromatic aberration may be corrected by placing behind it a concave lens of flint glass,

the latter, owing to its greater dispersive powers, not being so concave as the other is convex. Hence a certain amount of refraction remains, but the rays are rendered colourless.

The magnifying power of the astronomical telescope depends upon two things: the focal length of the object-glass, and the magnifying power of the eye-piece. Hence the great inconvenience of such telescopes is their length. The largest refracting telescope in England is that belonging to R. S. Newall, Esq., of Gateshead. The object-glass is 25 inches in diameter, the length about 30 feet, and its magnifying power is about 3000. When the moon is viewed through it, it appears as it would to the naked eye if it were only about 80 miles distant. There is a telescope in the Naval Observatory at Washington with a 26-inches aperture, and one still larger at Vienna. But a reflecting telescope 6 feet long will magnify as much as a refractor of 100 feet.

In a *reflecting telescope* a concave mirror is substituted for the convex lens. The principle on which it is constructed will be un-

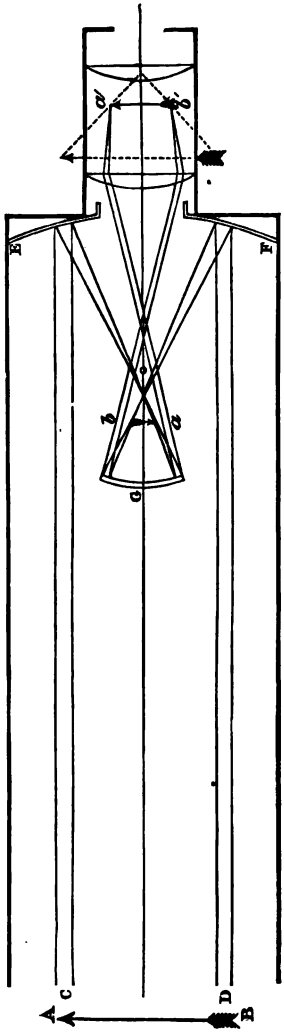


FIG. 9.

derstood from the diagram on the opposite page (Fig. 9). E F is a concave mirror, with an aperture in the middle, placed inside the large tube of a telescope; A B is a distant object, and C and D are rays flowing from it and falling upon the mirror. These rays are reflected back and form an inverted image at *b a*. From this image rays proceed to the reflector, G, and they are reflected back through the opening in the concave mirror. In the smaller tube a plano-convex lens is inserted, which causes the rays to converge and form a second image, *a′ b′*. The rays from this second image are rendered parallel by a second plano-convex lens, and, as in the refracting telescope, the object is seen under a large visual angle. The reflector, G, is made fast to a rod which runs along the side of the tube, and, by means of a screw on the outside, can be moved backward and forward so as to adjust the focal length.

The telescope just described is the Gregorian form; but for large instruments the Newtonian telescope is commonly preferred; in this case, the eye-piece is at the side. The open end being directed to a distant object, the rays fall upon a concave mirror as before. The reflecting mirror, however, is placed at an angle of 45° with the axis of the tube, and the rays falling upon it are converged into a focus in the side of the tube, and the image is magnified by the convex eye-glass. Herschel dispensed with the second mirror altogether by inclining the concave mirror so that the image might be viewed by the eye-glass. Lord Rosse's telescope is of this form. It is 54 feet in length, with a reflector, or *speculum*, as it is sometimes called, six feet in diameter, and is the most powerful instrument of its kind in the world.

Reflectors were invented by Newton in order to avoid chromatic aberration, for he was not acquainted with any means by which it might be corrected.

CHAPTER II.

Form and Size of the Earth: Map Projections.

Form.—It is a well-known fact that whenever we can obtain an uninterrupted view of the earth's surface the horizon, or line where the earth and sky seem to meet, is a perfect circle. This may be observed from the deck of a ship when it is far out at sea, or can be seen by the traveller when crossing an extensive plain. Every one who has visited the coast knows also that when a ship sails from port and is lost in the distance the top of the mast is the last part to disappear, and that if we could then climb some neighbouring eminence we might possibly get another view of the vessel. Such facts as these convinced even the ancient geographers that the earth was a sphere isolated in space, and its rotundity has been a recognised fact for nearly two thousand years. As the student advances in knowledge, proofs of this fact accumulate. Navigators have repeatedly sailed round the world, thus proving that at any rate it is isolated in space. The shadow of the earth may be seen during an eclipse of the moon, and this shadow is such as could only be cast by a spherical body. There is also the argument from analogy; the earth is a planet, and the other planets are spheres. Last of all, the law of gravitation necessitates the spherical shape of the earth. This law is exemplified in the dew-drop which hangs on a blade of grass, in the rain-drops which fall with every shower, in the tear that trickles down the cheek.

We have referred to the appearance presented by a ship when it leaves port—the tops of the masts are the last to disappear. If a vessel be coming into port, the masts appear first, and then the hull. Travellers notice a similar

effect upon the position of the stars. An observer at the Equator would notice the Pole-star on the northern horizon, but as he travelled northward this and other stars would seem to increase in altitude, just as the tops of the ship's masts appear to do when a vessel is approaching the shore, and for the same reason. In England the Pole-star is rather more than 50° above the horizon, and if ever the North Pole be reached that star will be almost exactly in the zenith. Looking southward, an observer would then notice the three stars which form Orion's belt on the horizon. In this country, these stars, when visible, are about 40° above the horizon, and at the Equator they appear in the zenith. It is this apparent change in the position of the stars that enables travellers to determine their latitude, or distance north or south of the Equator. A little reflection will show that the height of the Pole-star above the horizon, or the distance of Orion's belt from the zenith, at once gives the latitude. On the 21st March and on the 22d September the sun is vertical at the Equator. At these periods the distance of the sun from the zenith will give north or south latitude, as the case may be. At other times of the year, however, allowance must be made for *declination*, that is, the sun's distance north or south of the celestial equator.

Size.—It is evident, then, that if a person can by means of a sextant, or other astronomical instrument, find out the latitude of any place where he may happen to be, he can also find out the distance in degrees between any two places. Thus, supposing we take the latitude of Lizard Point as 50°, and that of the mouth of the Clyde as 56°, it is plain that the distance between these places is 6°; and if we knew the length in miles of a straight line joining these places, we could easily ascertain the length of one degree. Now, as every circle contains 360°, if we know the length of one degree upon the earth's surface it is easy to ascertain the earth's circumference.

In order to ascertain the length of a degree in miles, an arc of the meridian must be accurately measured, and this is done by means of a system of triangles—hence the pro-

cess is termed *triangulation*. The mode of procedure is something of this kind. A piece of firm level ground is selected, and a straight line 8 or 10 miles in length carefully measured; this is called a "base line." Such a line has been measured along the sandy shores of Loch Foyle. The next step is to fix upon some distant object which can be distinctly seen either by the naked eye or by means of a telescope, and the angles which this object makes when viewed from either extremity of the line are then determined by means of a theodolite. A triangle can now be laid down on paper, and the two angles and one side being known, the other two sides can be computed. Each of these sides may now form the base of other triangles, and in this way the whole country is surveyed. Signals on the Wicklow and Mourne Mountains, in Ireland, have been seen from Ben Lomond, Scaw Fell, and Snowdon. Thus the system of triangulation in Ireland has been connected with Great Britain; and the whole of England and Scotland has been covered with a network of triangles. And as these triangles are all laid down upon paper on a uniform scale, the length of a straight line connecting any two given points can easily be ascertained. Such a line, or *meridional arc*, as it is termed, connecting Shanklin Down, in the Isle of Wight, with the small island of Balta, in the Shetland group, has been measured; and, dividing the distance by the number of degrees between those places, the length of one degree is found to be about 69½ miles.

Meridian arcs have been measured in France, Russia, Hindostan, Peru, and Algeria. Quite recently the triangulation of Algeria has been connected with that of Spain. In the daytime signals were exchanged by means of sunlight reflected from mirrors; at night the electric light was made use of. The sides of the triangle which stretched across the Mediterranean were nearly 180 miles in length. By comparing the results obtained in various parts of the globe, the average length of a degree is found to be $69\frac{1}{10}$ English miles. We thus find that the circumference of the earth is about 24,876 miles, and its diameter 7912

miles nearly. A degree upon the earth's surface is not exactly the same in all places. From measurements made in the neighbourhood of Tornea, at the head of the Gulf of Bothnia, it was found that the length of a degree was 69¾ miles, while in Peru the length is only 69 miles. This shows that the earth is not a perfect sphere, but slightly flattened at the Poles. As it is the curvature of the earth which causes the stars to vary in altitude as the traveller moves northward or southward, it is evident that the less curved any particular portion of the earth's surface may be, the greater must be the distance travelled over in order to cause a given change in the position of a star. From careful measurements it has been ascertained that the polar diameter is 26 miles shorter than the equatorial diameter.

It is only within the present century that the exact shape of the earth has been determined. Newton, indeed, taught that on account of its motion upon its axis the equatorial diameter must be longer than the polar one, but the first attempts of the French *savants* to prove this by actual measurement led them to the opposite conclusion, and it seemed to them that the earth resembled in form a lemon rather than an orange. More careful measurements, however, with more perfect instruments than were available last century, have proved the truth of Newton's dictum. The same conclusion has been reached in a different manner by experiments with the pendulum.

The rate at which a pendulum oscillates depends mainly upon two things: the length of the pendulum, and the power of gravity—that is, the force which causes a body to fall to the ground. A short pendulum, other things being equal, vibrates more quickly than a longer one; but two pendulums of the same length ought to oscillate in equal times. It has been found, however, by experiment, that a pendulum does not vibrate in equal times in all parts of the earth, and that a seconds pendulum, for example, must be about $\frac{1}{10}$ of an inch longer in lat. 45° than what it is at the Equator; and that as we proceed towards the Poles we must continue to lengthen the pendulum if we wish it to

oscillate in correct time. The reason is, that gravity is greater nearer the Poles than at the Equator, and this, again, is owing to the fact that the Poles are nearer to the centre of the earth than the Equator is. A careful calculation of the rapidity with which a pendulum increases its rate of oscillation as we advance towards the Pole, coincides very nearly with the result obtained by calculating the rate at which degrees lengthen as we approach the Pole.

Density of the Earth.—Knowing the size of the earth, we are able to calculate its weight or density. The calculation depends upon the principle of comparing the attraction of the earth upon a small body with that exerted on the same body by some mass of definite size and weight. In 1774 the mountain called Schehallion, in Perthshire, was selected for this purpose by the Astronomer Royal of that time. A plumb-line was suspended on either side of the mountain, and its deflection from the perpendicular, owing to the attraction of the mountain mass, was carefully noted. The mountain was then accurately surveyed, and specimens of its rocks weighed. In this way it was possible to approximate to its weight. It was then calculated what the attraction would be in a mass the same size as the earth, supposing its density to be the same as that of the mountain, and it was found that it would be only about one-half that exerted by the earth. The mountain consists for the most part of granite, which has a specific gravity two and a half times that of water; it was therefore computed that the density of the earth was about twice that of granite, or five times that of water.

A few years later Mr Cavendish, a man equally distinguished in chemistry and mathematics, invented an experiment which, when carefully carried out, determines still more accurately the earth's density. Two small leaden balls, A B, are fixed at the extremities of a slender wooden rod, C, which is suspended by a fine wire, D. When the rod is perfectly at rest, two larger leaden balls, E F, placed on a moving frame, are brought near, and careful observations are then made to see how much

the smaller balls are moved out of their places by the attraction of the larger ones. By a movement of the turn-

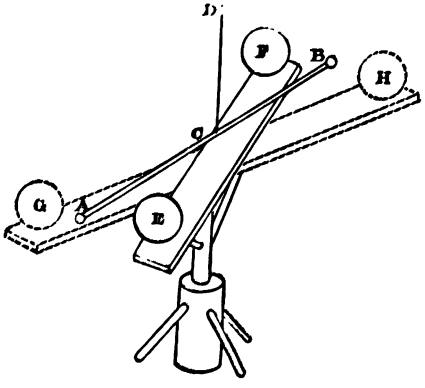


FIG. 10.

ing frame the larger balls can be brought into the position G H; and in each case the motion of the smaller balls is carefully observed. The experiment requires the nicest care, and has been carried out in the most complete manner more than once since Cavendish first proposed it. The suspended rod is enclosed in boxes so as to prevent any currents of air from affecting it, and the observer does not go near the apparatus, but makes his observations by means of a telescope. After carefully computing the amount of disturbance caused by the larger balls, this amount is compared with the attraction of the earth as indicated by the weight of the smaller balls. The result obtained is that the earth's density is about half that of lead, or, more precisely, 5·67 times that of water.

This result is pretty nearly the same as that obtained from the Schehallion experiment, but is considered more accurate. There is always some uncertainty about the composition of a mountain like Schehallion. Taken as a whole, its density may be that of granite; but it may also be more or less.

A third method of determining the earth's density was tried by the present Astronomer Royal a few years ago. The experiment depends on this principle, that if the earth be of the same density throughout, a pendulum would oscillate more slowly at the bottom of a deep mine than on the surface of the earth. For although the pendulum at the bottom would be nearer the centre of the earth, the absolute attraction would be less, seeing that all that shell of the earth's crust whose thickness is indicated by the depth of the mine has no effect upon the pendulum. If under these circumstances the pendulum vibrates quicker at the bottom of the mine, it must be because the earth's density increases towards the centre, and by noticing the rate of oscillation some approximation may be made as to the rate at which the earth's density increases, and therefore the whole density might be calculated. The experiment was tried at the Harton Coal Pit, near South Shields, in the year 1854, and the mean density of the earth was estimated at 6·565. It is evident, however, that this experiment labours under the same disadvantage as the Schehallion experiment. The material of which the earth is composed is not homogeneous—that is, all of the same kind—and hence the calculation is at best an approximation. It is generally considered, therefore, that the result obtained by the Cavendish experiment is the most reliable, and that the density of the earth is five and a half times that of water.

Projection of Maps.—As the earth is a globe, it is impossible to represent it on a flat surface with strict accuracy, and what is aimed at in the various methods of constructing maps, or projections, as they are called, is that the several regions of the earth shall be distorted as little as possible. In making these projections it is only necessary to project the lines of latitude and longitude, and the various countries are then laid down in the map according to the latitude and longitude of their several parts. In order to understand what is meant by projection, we must suppose the globe to be transparent, and to be cut in half by a transparent plane (A C, Fig. 11) passing through it; and just

as we see everything we look at through a pane of glass as if it were drawn upon the glass, so the parallels and meridians of the hemisphere on the side opposite to the spectator will appear to him as though drawn upon the plane of projection. There are five principal methods of projection in use:—the Orthographic, Stereographic, Globular, Conical, and Cylindrical.

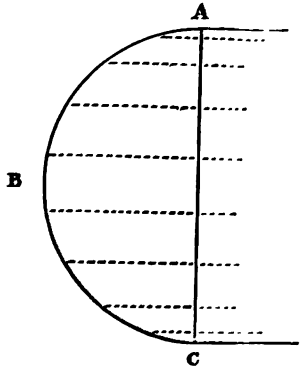


FIG. 11.

In the *Orthographic* projection the eye of the spectator is supposed to be at an infinite distance from the plane, so that the visual rays which traverse it in their passage from the different points of the hemisphere beyond come in parallel lines. The result is, as will be seen on inspecting the annexed diagram (Fig. 11), that equal spaces in the hemispherical surface are represented by unequal spaces upon the plane of projection. In this projection all the parallels are projected in straight lines, while all the meridians except the central one are elliptical curves. In the *Stereographic* projection the eye of the spectator is supposed to be on the surface of the globe, and exactly opposite the central point of the plane of projection. In this case (Fig. 12) the visual rays, instead of being parallel, all converge to the eye, and equal spaces are almost equally projected, while the inequality which still exists consists in those parts near the centre being crowded, instead of near the circumference, as before. The advantage of this projection is that the shapes of the countries are not distorted. As the orthographic projection causes equal spaces to be very much contracted towards the extremities of the projection, while in the stereographic they are greatly enlarged, it was thought that there must be some point between infinity and the surface of the globe where these

opposite defects might counteract each other. This point has been determined to be at a distance from the surface of the sphere equal to the sine of the angle of 45°, or, in other words, if the diameter of the sphere be divided into 200 parts, the point must be at a distance from the surface

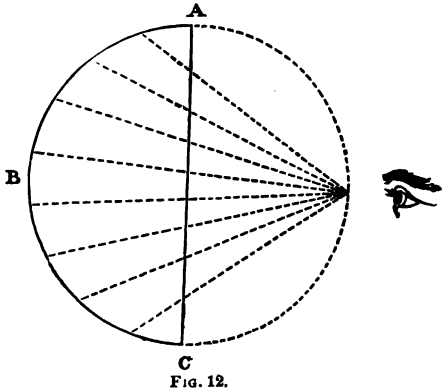


FIG. 12.

equal to 70 of these parts. In this, which is called the *Globular* projection, equal areas are represented by nearly equal spaces; whenever this projection, therefore, is used, there is very little disadvantage in making them quite equal, and the construction of the map is much simplified. When this is done the projection is called the Equidistant.

The advantages and disadvantages of these three projections may be thus summarized:—In the orthographic projection the parallels are straight lines, and the meridians ellipses. Equal spaces on the sphere are represented by unequal spaces, the consequence being that while the central parts are nearly correct, those at a distance from the centre are much distorted. In the stereographic projection the parallels and meridians are projected in arcs of circles. The parts near the circumference are much too large in proportion to those near the centre, but the *forms* of the several regions are better preserved than in the

orthographic projection. In the globular projection the parallels and meridians are projected in ellipses of small eccentricity; in the equidistant, these are projected in arcs of circles. In both cases equal spaces on the sphere are represented by equal, or nearly equal, spaces on the projection, and, accordingly, the relative sizes of the various countries are more correctly given than in other projections, but the forms of the countries are greatly distorted, and the more so the farther from the centre. However, from the ease with which the globular, or, more properly, the equidistant projection can be executed, it is the one generally adopted in maps of the whole globe.

In maps of separate countries the *Conical* projection is sometimes used. In constructing this projection it is usual to make the cone coincide with the central or mean parallel of the country it is intended to represent, and, accordingly, as the cone may be opened out, or *developed*, into a flat surface, all the distances along that parallel are as exactly laid down on the map as on the sphere itself. Of course, those to the north and south of the central parallel are a little too long. This projection is often used in constructing maps of Europe.

The *Cylindrical* projection was introduced by Mercator, whose name it bears, in 1556. It was first intended merely for the use of navigators, in order that they might be enabled to lay down their course, which it was impossible to do in ordinary maps, where the parallels and meridians are curves. We can easily understand the nature of this projection if we suppose an ordinary hollow indiarubber ball to have the lines of latitude and longitude marked upon it. Suppose, now, we cut out the spaces representing the arctic and antarctic circles, and then stretch the ball over a cylinder of the same diameter as itself. It would then be seen that the equatorial parts fitted the cylinder with little or no stretching, but that as we receded from the Equator the meridians would be widened out and become parallel to each other. If we could now render the indiarubber envelope rigid, and could then slit it up and unfold it, we should have a cylindrical

projection of the globe. As the meridians converge as we approach the Poles, while in this projection they remain parallel, it is necessary, in order to preserve the shape of the countries, that the degrees of latitude on the projection should be lengthened in the same proportion as the degrees of longitude diminish on the sphere, and this is done with little difficulty. It will be seen from what has been just said that in a map on Mercator's projection the forms of the several countries are perfectly accurate, but that the magnitude of the regions near the Poles are greatly exaggerated.

In the projections of which we have spoken we have supposed the plane of projection to be at right angles to the Equator. This projection is said to be on the plane of the meridian; but as a globe may be divided into two hemispheres in a number of different ways, so we may have as many different planes of projection. Thus, if the plane be supposed to divide the globe at the Equator, we have a polar projection in which one of the Poles is the centre. Sometimes a particular place, such as London or Paris, is selected, and the hemisphere projected on the plane of the rational horizon of that place; in other words, maps of the world are constructed with London or Paris as the centre of one of the hemispheres.

It would obviously be out of place in a manual like this to enter into details respecting the construction of the different projections; but we may mention that while the globular projection is very difficult of construction, that modification of it called the equidistant is comparatively easy, since both the parallels and meridians are perfect arcs of circles. We first describe a circle to represent the hemisphere, and then draw two diameters at right angles to each other, one to represent the Equator, and the other the central meridian. Then if we divide each of the quadrants and each of the semidiameters into nine equal parts, we shall only have to describe a number of arcs, each passing through three given points, and the projection is complete. In this case the distance between the parallels and meridians respectively is 10 degrees.

CHAPTER III.

The Visible Heavens.

If we observe the sky attentively for any length of time on a clear night, we shall notice that the stars seem to have a motion from east to west. Certain stars will appear above the eastern horizon and gradually rise higher and higher in the heavens. Others will be seen to descend towards the west, and at length to sink below the horizon. The Pole-star is the only one that seems at rest, and it will be noticed that those which are in its neighbourhood, as the cluster called the Great Bear, for example, move in a circle round the Pole-star, and remain visible the whole of the night and every night. Another bright star, named Capella, is at one time almost in our zenith, but when it has moved round to the opposite part of the circle which it describes it almost touches the northern horizon. Stars at a greater distance from the Pole dip below the horizon and are invisible during part of their course. One constellation is very conspicuous in the winter months in the south part of the sky. It is called Orion, and may be known by the three bright stars in a line which form its belt. If these are noticed it will be seen that they describe an exact semicircle, one-half of their orbit being always below the horizon. Still farther south the stars describe arcs of circles which become smaller and smaller as we approach the southern horizon, till some just rise for a short time and then again disappear.

It would appear, then, that all stars seem to move in circles of various sizes round an axis one extremity of which points to the Pole-star. That the courses described are circles or portions of circles is proved by the use of an instrument called the *Equatorial.* This is a large telescope

fixed upon an axis which points to the Pole-star—or, more exactly, to the celestial pole, round which the Pole-star revolves in a very small circle. The telescope turns round upon the axis in any direction, and it may be raised or lowered in a vertical plane, so that it can be directed to any point in the visible heavens. The instrument is attached to machinery which causes it to move slowly in the direction in which the stars appear to move. Now, if the telescope be directed to any particular star, and the motion so regulated as to agree with the time in which the star appears to move across the sky, it is found that the star always keeps in the field of vision. Hence, as we have said, the path of the star must be a portion of a circle. The Equatorial also shows that all the stars move at a uniform rate. If after observing one star we direct the telescope to another, the motion is still the same. They all appear to move as if in one piece, as if they were fixed points in a hollow sphere.

Constellations.—To the ordinary observer the stars seem so numerous that it would appear hopeless to recognise any but one or two of the brightest; but just as geographers map out the surface of the globe and give names to the various countries and seas, so astronomers map out the stars into groups called constellations. We have mentioned two of these—the Great Bear and Orion; the Pole-star belongs to another called the *Little Bear*, and Capella is the brightest star in the constellation *Auriga*, or the charioteer. It is also customary to name the stars in each constellation after the letters of the Greek alphabet, according to their degrees of brilliancy, the brightest being termed α (Alpha), the next brightest β (Beta), and so on. In the annexed diagram (Fig. 13) the central star is the Pole-star. The *Great Bear* is seen to the south; the two front stars are called the pointers, since they always point to the Pole. Vega, the bright star opposite to Capella, is the principal star in the constellation *Lyra*. Three out of the four stars seen in the neighbourhood of Vega belong to the constellation *Draco*, the Dragon, which curves round the celestial pole; the other—the one farthest from the Pole—

belongs to the constellation of *Hercules.* A straight line from the Pole-star, passing near the tip of the tail in the

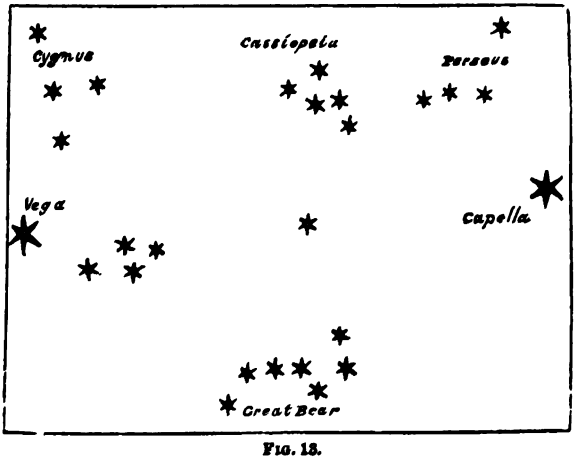


FIG. 13.

Great Bear, leads to Arcturus, a very bright star, being the principal one in the constellation *Boötes*, or the Huntsman.

Let us now turn to the constellation of *Orion:* it is a four-sided figure, with the three stars forming the belt lying in a south-east and north-west direction. The brightest star in the constellation is named Betelgeuse, and is at the north-east corner. If a line be drawn through the belt and continued south-east, it cuts Sirius, the brightest star in the sky: it belongs to the constellation *Canis Major.* Another bright star to the north-east of Sirius, and to the east of Orion's belt, is Procyon, belonging to *Canis Minor.* Due north of Procyon two bright stars are visible; these are Castor and Pollux, in the constellation of the *Twins* (Gemini.) If we suppose a line to be drawn from Sirius to Orion's belt and continued in that direction, it leads to a bright star in the constellation of the *Bull* (Taurus) which has been named Aldebaran. The

cluster of stars which is close to it are the Hyades, and farther to the north-west are the Pleiades, which also belong to Taurus.

The Zodiac.—It will appear from what is stated in the following chapter that the sun, besides its apparent daily motion from east to west, has an apparent yearly motion among the stars. The path followed by the sun in its apparent annual motion is called the *Ecliptic*, because eclipses take place when the moon is on this line. The space for nine degrees on either side of this imaginary line is called the *Zodiac*, and it is in this region that the planets perform their annual revolutions. The zone called the zodiac was divided by early astronomers into twelve equal parts, called signs of the zodiac, and each sign was named after the constellations which occupied the space. These constellations are Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces. As the ecliptic is a great circle, it bisects the celestial equator, and the two points where the circles intersect were formerly in the constellations of Aries and Libra respectively. In summer the sun was in Cancer, in mid-winter in Capricornus. Owing to a cause which we shall afterwards explain, the constellations of the zodiac do not now coincide with those divisions of the zodiac to which they give their names; hence there is a distinction between the *signs* of the zodiac and the *constellations* of the zodiac.

The position of any place upon a map may be determined when the latitude and longitude are given. Astronomers have a similar method of fixing the position of a heavenly body, but they use the terms declination and right ascension. *Declination* corresponds to latitude, and is the distance north or south of the celestial equator. *Right Ascension* corresponds to longitude, and is measured from a given point, but differs from longitude in two respects: it is measured only in one direction, and it is not measured in degrees, but in hours and minutes. The place from which right ascension is measured is called the *First Point of Aries.* It is that point in the heavens

where the ecliptic and celestial equator cut each other at the vernal equinox, and is the position occupied by the sun at noon on the 21st March.

The instrument generally made use of in order to determine the declination and right ascension of a heavenly body is the *Transit Circle.* It consists of a telescope fixed firmly on an axis which points due east and west. The telescope moves freely upon the axis, but only in a vertical plane, so that it always points to the meridian. On one side of the telescope there is a vertical circle properly graduated, so that the declination of any object may be determined. Thus, suppose we swing round the tube until it points to the Pole, and then see that the direction of the telescope coincides with 90° on the circle, we may turn the tube back again to 0°, and it is then pointing to the celestial equator, and we can thus determine the position of any heavenly body with respect to the equator, in other words, its declination. In determining right ascension we make use of an *astronomical clock.* This clock is set to sidereal time,—that is, the exact time which it takes a star which is on the meridian to come back to the meridian again,—is divided into twenty-four sidereal hours, and each hour is divided into minutes and seconds. When the transit instrument points to the first point of Aries, the clock indicates 0 hrs. 0 mins. 0 secs. A star which comes on the meridian an hour later is said to have a right ascension of one hour, and thus the R. A. of a star may be two, three, or any number of hours up to 23 hrs. 59′. It will thus appear that by means of the transit instrument the declination and R. A. of any star may be determined by one observation.

The terms longitude and latitude are used in astronomy, but in a different sense to declination and right ascension. By celestial latitude is meant the distance of any heavenly body north or south of the ecliptic, and by celestial longitude the distance of any body from the first point of Aries, measured in degrees on the ecliptic, reckoning from east to west up to 360 degrees. It therefore differs from R. A. in being measured in degrees, not time, in being measured

on the ecliptic instead of on the celestial equator, and in being measured in the opposite direction, or from east to west instead of west to east.

Longitude.—In the previous chapter we referred to the means of determining latitude, or the distance of any place north or south of the equator, by means of a sextant. The determination of longitude is a more difficult process. Longitude is the distance east or west of a given place, and is merely the difference in time between any two places. When the sun is on the meridian at any place it is noon, or twelve o'clock; and as the sun appears to rise in the east, to set in the west, and then to reappear next morning after an interval of twenty-four hours, it passes successively over the meridian of every place upon the globe in that time, and hence it is noon at places to the east of Greenwich sooner than at Greenwich, and at places to the west later. The sun travels round the world in twenty-four hours; and as the circumference of the earth, like every other circle, contains 360°, it passes over 15° in one hour. If, therefore, a place is 30° to the east of Greenwich, we know that its time must be two hours earlier; and, conversely, if the time be two hours earlier, its longitude must be 30° east. This suggests one way of finding longitude which is very commonly adopted at sea. The captain of a vessel takes with him a chronometer set to Greenwich time, and he makes his daily observations about noon. If he finds that the sun comes on the meridian say at two o'clock by Greenwich time, he concludes that he is 30° west of Greenwich. A second method is to notice the position of the moon among the stars. In the *Nautical Almanac* the distance of the moon from certain stars in her course is given for every third hour in Greenwich time. The sailor observes the position of the moon, and after making the necessary corrections for refraction and parallax, he refers to his almanac to see at what hour, Greenwich time, the moon would occupy this particular position. Having ascertained this, he refers to the local time, and, comparing this with the Greenwich time, finds his longitude. In this case he dispenses with the chronometer. A third method is to

watch for the occultation of certain stars, or the eclipses of some of Jupiter's satellites, and then, observing in his almanac the time at which these are visible at Greenwich, he compares this with local time as before.

On land the transit instrument is generally used, and observations can be made with the greatest accuracy, especially if use be made of electricity.

In order to ensure accuracy in observations, a *Chronograph* is generally used. This consists of a barrel covered with paper which is made to revolve rapidly. By means of a galvanic current, a pricker is made to puncture the paper at each beat of the sidereal clock, and there is a break at the beginning of each minute, so as to avoid confusion. The observer watches until a star crosses the wires of the eye-piece of his instrument, and then, pressing a spring, makes an additional puncture on the paper. He can thus tell, to the fraction of a second, the exact time when the transit took place. Suppose two observers wish to ascertain the distance in degrees of longitude between New York and San Francisco. The two observatories are connected by electric wires. When a star crosses the wires of the transit instrument at New York, the chronograph is punctured, and the electric current conveys the message to San Francisco by puncturing a chronograph there. When the transit takes place at San Francisco, the message is sent back to New York by the same means. As the electric current takes some definite time to travel between the two places, the exact interval between the transits is not the interval between the times at which the message was despatched from and received at New York; but due allowance is easily made, and the exact difference of time between the two places ascertained.

Planets.—We have mentioned that the fixed stars all appear to move in the same direction, and with a uniform motion. In very early ages, however, astronomers noticed that there appeared to be some exception to this rule. There were certain bodies which at first sight had all the appearance of stars, but their movements were very irregular, and to them they gave the name of planets, or

"wanderers." Of these five were known to the ancient world—Mercury, Venus, Mars, Jupiter, Saturn. The first, because it had the swiftest motion, was named after the messenger of the gods; the next, on account of its brilliancy, was named after the goddess of beauty; Mars probably owes its name to its ruddy or blood-red hue; Jupiter was considered the largest, as it is at times the most brilliant, and was named after "the father of the gods and the king of men." Saturn, which appeared small and insignificant, was named after the father of Jupiter.

Some of the Greek astronomers believed that the planets moved in circles round a centre, but do not seem to have believed that the earth itself was a planet. Ptolemy, who lived about two hundred years after Christ, and who was acquainted with the fact that the earth was round, thought that Venus, Mercury, and the sun were attached to a kind of bar, at the extremity of which was the earth, and that Venus and Mercury moved round some centre in this bar, while at the same time they, along with the sun, were carried round the earth. A similar arrangement was invented to explain the movements of the other planets. Tycho Brahé, a distinguished Danish astronomer, who lived in the sixteenth century, advanced a step nearer the truth. He taught that all the planets moved round the sun, but that the sun, with the planets as satellites, moved round the earth, which was fixed. Copernicus (1473–1543) was the first who taught that the sun is the centre of the whole planetary system, including the earth; but not until a century later was this opinion generally accepted. Even after this, however, there were several difficulties connected with the motion of the planets that could not be explained, arising from the fact that astronomers thought the planets moved in perfect circles. It was reserved for Kepler, after carefully studying the observations and calculations of his predecessors, to show that the motions of the planets could be perfectly explained by supposing them to move in ellipses. His three famous laws respecting the movements of the planets—laws which were afterwards explained and proved by Newton—are these:—

1. Each planet describes round the sun an orbit of elliptical form, and the centre of the sun occupies one of the foci.

2. The areas described by the radius vector (the imaginary line joining the planet and the sun) of a planet are proportional to the time taken in describing them.

3. If the squares of the times of revolution of the planets round the sun be divided by the cubes of their mean distances, the quotient will be the same for all the planets.

The first law relates to the form of the orbits of the planets, and needs no explanation; the second conveys in precise language the fact that the nearer a planet approaches to the sun the quicker it moves, and thus suggests that there is some relation between the rate at which the planets move in their orbits and the distances of the planets from the sun; the third law states precisely what this relation is.

Kepler's third law is a very important one, as by its help we are enabled to measure the distance of the sun. It does not itself give us that distance, but it gives us a proportion by means of which we are able to determine it. Thus, knowing the periodic times of the Earth, Venus, and Mars, that is, the length of time required for these bodies severally to move round the sun, we find by calculation that if the distance of the earth be taken as 100, that of Venus must be 72. We find also that when Mars is in opposition to the sun its distance from the earth is sometimes only one-third the distance of the sun from the earth. If, therefore, we could ascertain the distance of Mars when in this position, we could easily find the sun's distance. Before proceeding further with this subject, however, it may be well to consider how the distance of the moon is ascertained, as it is the nearest to us of all the heavenly bodies.

Distance of the Moon.—In speaking of the process of triangulation, we mentioned that a base line was first measured, and that a distant object being fixed upon, the angles which this object made, when viewed from either extremity of the line, were then observed, and one side

and two angles of a triangle being determined, it was easy to find the length of the remaining sides. Now, the method employed to ascertain the distance of the moon is very similar to this. Thus, let the curve S S′ represent

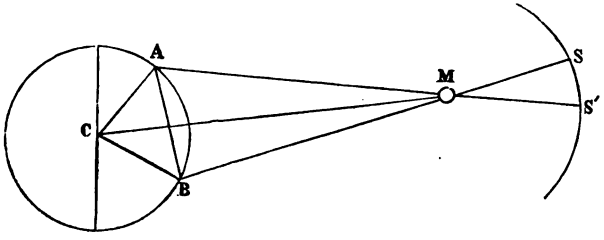


FIG. 14.

the position of two stars in the heavens, C the centre of the earth, and M the moon; and let A be the position of an observatory at Greenwich or some other place in Europe, and B the observatory at the Cape. Now, if the moon be observed from A, its position among the stars will appear to be at S′; if observed from B, its position will appear to be at S. This apparent change in position is represented by the angle S M S′, which, of course, is the same as the angle A M B. Knowing the size of the earth, it is easy to calculate the distance from A to B; and the angles M A B, M B A can be ascertained from observation and calculation; hence, as before, we have two angles and one side, and from this we can calculate the length of A M or B M, in other words, the distance of the moon from Greenwich or the Cape. Astronomers, however, find it convenient to make all their calculations of distance in reference to the earth's centre. Let us therefore draw the lines A C, B C, M C. The angle A M C is termed the moon's *parallax* as observed from Greenwich, and the angle B M C the moon's parallax as observed from the Cape. The sum of the two is, of course, the angle A M B, which has been found by careful observation to be about one and a half degrees.

The method by which the moon's distance is actually measured is something of this kind: A certain value is given to C M, the distance A C is known from the size of the earth, the angle C A M is obtained as before. With these two sides and one angle given, the remaining angles of the triangle can be calculated, and thus the angle A M C is found. In a similar manner the angle B M C is calculated. If the sum of these angles equal the whole angle A M B, as obtained by observation, the value assigned to C M is correct. If the sum be less or more, another value must be assigned to C M, and calculation gone over again until the exact value is found. In this way it has been ascertained that, in round numbers, the distance of the moon is 240,000 miles from the earth. When we have ascertained the distance of the moon, it is easy to calculate its size; for, knowing the apparent size and the distance, its real size is easily found. The apparent diameter of the moon is about half a degree, its real diameter is about 2000 miles.

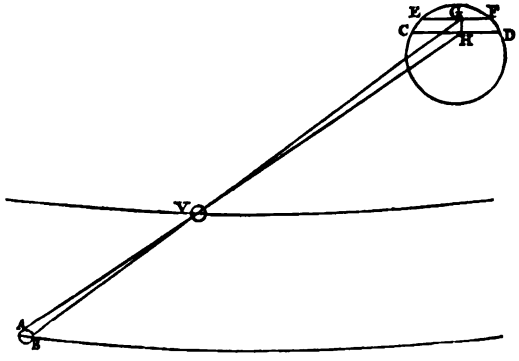
When Mars is in opposition its position can be ascertained in precisely the same manner as we measure the distance of the moon. Observations are taken at Greenwich and the Cape, and the position of the planet with respect to certain stars carefully noted. We then get the parallax of Mars, and thus its distance. And as we know from Kepler's third law that this distance is sometimes just one-third the distance of the sun from the earth, we are enabled to calculate the distance of the sun. The sun's distance was measured in this way in the year 1862, and the result obtained was 91,500,000 miles, a result which is probably not very far from the truth.

Transit of Venus.—Many people think that the most accurate method of determining the sun's distance is by means of the transit of Venus. As Venus moves round the sun in an orbit that comes between the earth and the sun, it is easy to understand that at certain times it must cross the sun's disc, and will then appear as a small black spot. If the orbit of Venus were in exactly the same plane as the earth's orbit, this transit, as it is called, would

take place every eight years, but the two orbits are inclined to each other at a slight angle. The consequence of this is, that the phenomenon takes place at irregular intervals, which, however, astronomers can calculate. A transit was known to have taken place in 1631, though it was not observed, and Kepler foretold that the next appearance would be in 1761. A young Lancashire astronomer named Horrox, however, came to the conclusion that a transit would be visible in 1639, and his prediction came true, though he alone saw it. Dr Halley in 1716 pointed out, in a paper published by the Royal Society, that the sun's distance might be determined by observations of the transit, and he mentioned that the phenomenon would occur in 1761 and again in 1769. Some observations were made in 1761, but they were not very successful. In the transit which took place eight years later, however, great care was taken, and the result, upon the whole, was very satisfactory. One expedition was sent out to Lapland, and another, under Captain Cook, was sent out to the South Pacific, where a station was selected on the island of Otaheite. From these observations the sun's mean distance was calculated to be 95,500,000 miles, but more recent investigations connected with the velocity of light seem to show that this distance is too great by at least 3,000,000 miles. Another transit took place in 1874, the results of which are not yet officially announced, but it is generally understood that the result obtained in 1862 by making use of the parallax of Mars is somewhere near the truth. The next transit will take place in 1882; and as there will not be another for above 100 years, astronomers are looking forward to it with great interest.

The principle on which the calculation is made may be easily explained. Let the circle C E F D (Fig. 15) represent the sun, V the planet Venus, and A B the earth. If the planet is viewed from the point A, it will seem to cross the sun's disc along the line C D. If viewed from B, along E F. Of course, both the earth and Venus are moving; but as the rate at which they move is known, and as Venus moves the quicker of the two, it is easy to cal-

culate at what rate Venus will appear to cross the sun. In making the observation, the exact time at which the planet



appears to touch the sun at C, and the length of time it takes to cross the disc, are noted by the observer at A. The observer at station B notices the time it takes the planet to cross from E to F. From a comparison of these times with the rate at which the planet is moving we get the exact part of the sun's disc where the lines cross, and thus the perpendicular distance between them. Now, we have mentioned that, according to Kepler's third law, if the distance of the earth from the sun be 100, then the distance of Venus must be 72. Let us suppose that A is a station in Lapland, and B a station in the South Pacific. Knowing the size of the earth, we can calculate the distance of a straight line joining these points, which would be about 7000 miles. We now get the following proportion:—As A V is to A B, so is V H to G H, or 28 : 7 : : 72 : 18. We thus find that the length of the perpendicular between the parallel lines is 18,000 miles. Knowing the length of this perpendicular, it is easy to calculate the length of the sun's diameter, and from this the distance of the sun is computed. The diameter of the sun is about 850,000

miles, or more than one hundred times the diameter of the earth. In bulk, therefore, it is more than one million times as large; and although it has not the same density, still it weighs as much as 300,000 globes like the earth.

Knowing the real size of the sun, and comparing this with its apparent size, we are able to compute its distance; and so far as we may judge from the results obtained from the last transit of Venus, the mean distance of the sun is about 92,000,000 miles, certainly not more than 92,500,000. In the opinion of many astronomers, however, the velocity of light affords a more accurate means of calculating the sun's distance. From a careful consideration of the aberration of light and the eclipses of Jupiter's satellites, as we shall hereafter explain, it has been calculated that light comes from the sun to the earth in 498 seconds. Foucault, from experiments with revolving mirrors, came to the conclusion that light has a velocity of 185,000 miles per second; the mean distance of the sun, therefore, must be about 92,130,000 miles. More recently Cornu, adopting Fizeau's method of measuring the velocity of light by means of a rapidly revolving wheel, has fixed the rate at 186,670 miles per second. This would make the sun's distance nearly 93,000,000 miles.

We thus see that it is possible to ascertain the distance of the sun and moon; and as there is a relation between the periodic times of the planets and their distances, it is possible, when the earth's distance from the sun is known, to calculate the distance of any of the other planets. But all these methods fail when applied to the stars. We shall find afterwards that the nearest to us of all the fixed stars, so far as is at present known, is at least 200,000 times farther distant from us than the sun.

CHAPTER IV.

MOTIONS OF THE EARTH.

In the preceding chapter we have assumed that the earth is one of the planets, and that, like Venus or Mars, it revolves round the sun in an elliptical orbit. It may be well, however, to consider some of the arguments that are brought forward to prove that the earth is not the centre of the universe, as was once supposed.

Diurnal Motion of the Earth.—The sun appears to move round the earth once in twenty-four hours, but when we reflect upon the size and distance of the sun we see that this must be impossible. In the first place, it is contrary to the laws of gravity that a large body should move round a smaller one. The two would move round their common centre of gravity, and that lies within the sun's mass. Again, supposing it were possible that the sun could move round the earth, we can hardly realize the immense speed at which it must move in order to accomplish an orbit of about 600 million miles in twenty-four hours; and all this to produce an effect which would be precisely the same if the sun were stationary and the earth turned upon its axis. Copernicus, as we have already stated, was the first to announce that this was the case. When the telescope was invented it could clearly be seen that the other planets had a motion upon their axes, and hence the statement made by Copernicus was upheld by Galileo until he was compelled to retract by the tortures of the Inquisition. The opponents of Galileo contended that if the earth really turned round from west to east, then a stone dropped from a high tower ought to fall to the westward, for that while it was falling the earth was moving. Galileo answered that

the stone partook of the motion of the earth, and therefore would fall precisely at the foot of the tower. Sir Isaac Newton, however, declared that if proper precautions were taken it would be found that the stone would fall a little to the eastward; for the top of the tower, describing a greater circle than the foot, would move with greater velocity, and that the stone in dropping to the ground would still retain this greater velocity. A series of experiments were now undertaken, with more or less success, to test the truth of Newton's statement; and from these Laplace calculated that the chances are 8000 to 1 that the earth turns upon its axis.

Another argument brought forward to prove the earth's motion is the shape of the earth, which we have seen is not that of a perfect sphere. It is said that its present form is precisely that which a fluid mass, as the earth is supposed to have been at one time, would have assumed supposing it were made to rotate rapidly. Sir John Herschel goes farther, and proves that even supposing the earth had always been in the same solid form that it now is, yet its daily rotation would have produced just the form which it now has. All these considerations are sufficient to make the earth's rotation a subject of almost positive certainty, but an ingenious French philosopher, M. Leon Foucault, has devised two experiments—one with the pendulum, and the other with the gyroscope — which render the motion of the earth visible to the eye. The pendulum experiment depends upon the fact that if a pendulum is set in motion it will concontinue to vibrate in the same plane, even though the point of suspension be altered. A heavy weight was suspended by a fine wire from the dome of the Panthéon in Paris, and a fine point at the bottom of the weight was made to leave a mark in sand at each swing. The marks successively made in the sand showed that the plane of oscillation varied with regard to the building; and as we know that the plane itself could not vary, the appearance must have been caused by the movement of the building itself. A full explanation of this experiment

as well as of the gyroscope is given in the appendix to Sir George Airy's *Popular Astronomy*.

Annual Motion.—We may accept it, then, as a settled truth that the apparent motion of the sun from east to west, as well as of the stars, is due to the motion of the earth in an opposite direction, or from west to east. If we compare, however, the motion of the sun with that of the stars, we see some points of difference. The stars, when they reach the meridian, have always the same declination. If any particular star is seen by means of the transit instrument at a certain hour by the astronomical clock, we may look at that star a month later, and we find it in the same place; its declination and right ascension have not altered. But this is not the case with the sun. We know that it is higher in the sky in summer than in winter. In spring and autumn its place is on the celestial equator; in midsummer it is 23½° north of the equator; in midwinter it is 23½° south. But this is not all. The exact time in which the earth makes one revolution upon its axis is 23 hours 56 minutes. This is proved by the fact that the stars seem to perform a complete revolution in that time, but the interval between noon one day and noon the next day is twenty-four hours. This difference of four minutes is due to an apparent motion of the sun to the east about one degree every day, a motion quite independent of its apparent daily motion from east to west. Thus when the earth has made one revolution upon its axis, the sun, instead of being on the meridian, is a degree to the east, and it takes about four minutes to bring it on the meridian. This apparent eastward motion of the sun can be observed through a good telescope during the day, and it is seen that each day the sun changes its place among the stars. It may also be traced by observing the stars at night. If we observe any that come on the meridian at a given hour by ordinary time, we shall notice that next night at the same hour they will have passed the meridian. If we cease observing for about a month, we shall notice a great change. Some stars that on the previous occasion were

near the western horizon will have disappeared. New constellations will have risen in the east, while stars which before were on the meridian will now be considerably to the west of it. After twelve months the stars reappear in their former positions, the sun having described a complete circle among them. If we could trace on a map of the stars the path which the sun has appeared to describe in the course of the twelve months, we should find that it was a great circle cutting the celestial equator in two points, but at two other points diverging from it to a distance of $23\frac{1}{2}°$. This apparent path of the sun among the stars is called the *Ecliptic* (see p. 178).

We have seen that the sun's apparent daily motion is due to a real motion of the earth on its axis; it is reasonable, therefore, to suppose that this apparent annual motion is also caused by a movement of the earth. Now, a little reflection will show that the apparent motion of the sun among the stars in the course of the year would be precisely the same whether we suppose the sun to be moving round the earth or the earth to be moving round the sun. But many of the arguments brought against the supposition of the sun's daily motion apply also to the supposition of its yearly motion. It seems almost superfluous to bring forward any further arguments in favour of a truth which no one now doubts; but there is one proof of the earth's motion, indirect, indeed, but none the less conclusive, which is so interesting in itself that a few words may be devoted to it: we refer to the *aberration of light.*

Dr Bradley, who succeeded Halley as Astronomer Royal in 1741, had been engaged some years previously in endeavouring to find out the parallax of some of the fixed stars. To his surprise he discovered, by very careful observation, that the stars were not fixed, but that they revolved in minute circles about 40″ in diameter. For a time this appearance was inexplicable, but at length he discovered that it was owing to the annual motion of the earth, combined with the fact that light had a definite velocity. Thus let S be a star in the zenith (Fig. 16), and A B the tube of the telescope. If the earth

were at rest the telescope would be so too, and it would not matter how long the ray of light were in passing from A

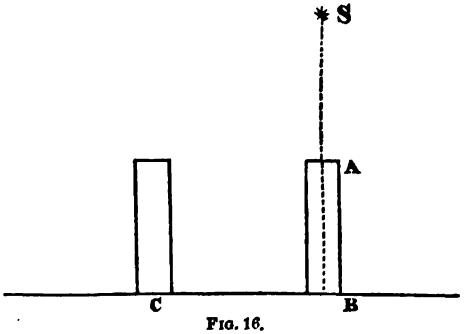


FIG. 16.

to B; we should see the star on looking through the tube. If, however, while the ray was passing from A to B, the tube were moved to C by the motion of the earth, the light would strike against the tube, and the star would be invisible; and in order to see the star the tube must be inclined a little. Thus in Figure 17 we will suppose the

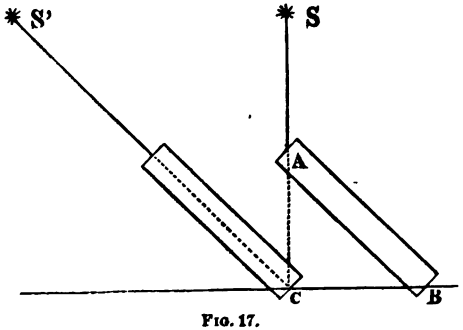


FIG. 17.

tube inclined in the direction A B. Then if, while the ray of light is passing from A to C, the telescope moves on from B to C, the ray would reach the eye of the spectator at C. And as an object always appears in the

direction in which the ray of light appears to come, the star, instead of appearing to be in its true position, S, would appear at S′, a little in advance; and as this will be the case from whatever part of the earth's orbit the star is viewed, it follows that stars in the zenith will appear to describe minute circles round their real positions, while those in other parts of the heavens will appear to describe ellipses of greater or less eccentricity. From the size of these minute circles—which as seen in the zenith have, as we have said, a diameter of about 40″, astronomers are able to compute the relative velocities of light and of the earth's motion in its orbit; and it is found that the velocity of light is about 10,000 times as great as the earth's velocity, or about 186,000 miles in a second.

The path which the earth follows in its annual revolution round the sun is called the earth's orbit, and the space included within the orbit is called the plane of the earth's orbit, or sometimes the plane of the ecliptic, for it will be seen on a little reflection that it is on the same level as the apparent path of the sun among the stars. As the earth moves along it spins on its axis, making one revolution in 23 hours 56 minutes. If the earth's axis were perpendicular to the plane of the ecliptic, the sun would always shine upon the Equator, and the celestial equator and ecliptic would coincide. But we have seen that they are inclined to each other at an angle of 23½ degrees. The reason is, that the earth's axis is inclined 23½° from the perpendicular, or, in other words, it makes an angle of 66½° with the plane of the ecliptic. It is to this inclination of the earth's axis that we owe the variety of the seasons.

The Seasons.—The reasons why it is hotter in summer than in winter are mainly two: (1) because the sun is more vertical; (2) because the days are longer. We all know that the sun is much hotter at noon than it is in early morning, yet it is the same distance from us in both cases; but at noon its rays pour down upon us with more effect. For the same reason, in summer its rays are much warmer than in winter. Again, the greater length of day in summer allows the heat to accumulate, and in the short

night there is not such a long period for the earth to cool as there is in winter time. The following diagram will

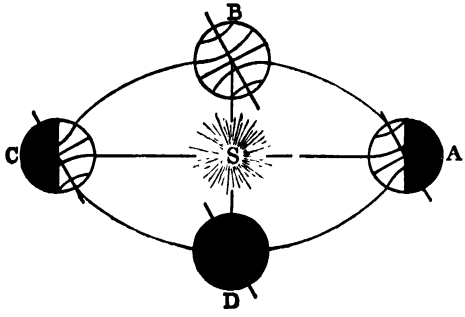


FIG. 18.

explain both why the sun is more vertical in summer and why the days at that season are longer than at any other. Let S represent the sun, and A B C D the earth in four different positions in its orbit; the four straight lines are to represent the earth's axis, and to show the inclination of the axis to the plane of the ecliptic. It will be noticed, also, that the axis is always parallel to itself. When the earth is at A, the North Pole is inclined to the sun, and the sun's rays strike perpendicularly upon the tropic of Cancer, which is $23\frac{1}{2}°$ north of the Equator: it is then summer in the northern hemisphere. At C the vertical rays of the sun strike upon the tropic of Capricorn, $23\frac{1}{2}°$ south of the Equator: it is then summer in the southern hemisphere, and winter north of the Equator. In the other two positions neither pole is inclined to the sun, which is then perpendicular over the Equator. These are the autumn and vernal equinoxes. We may now explain how it is that the lengths of day and night vary with the seasons.

If we hold a globe up before a candle, we see then only one-half of it can be illuminated at the same time. It is so with the earth: only one-half of it can be lighted up at

the same time by the rays of the sun; the other half is in darkness. The line which separates the illuminated part from the part in shadow is called the *circle of illumination*, and this circle is what mathematicians call a great circle: its centre coincides with the centre of the earth. When the earth is in the summer solstice (position A) the sun shines directly upon the tropic of Cancer; a point on this circle must therefore for the time be the centre of the circle of illumination, which will thus stretch 23½° beyond the North Pole, but will fall short of the South Pole by the same distance. As the earth turns upon its axis all parts of its surface that come within the circle of illumination will have day, all beyond it night; and a glance at the diagram will show that so long as the earth remains in the position A, a space round the North Pole, within the Arctic circle, will have continual day, while within the Antarctic circle there will be continual night. At the winter solstice the reverse of this happens; the North Pole is shrouded in darkness, while the South Pole has one long day. When the earth is at the equinoxes, then, since the sun shines at these periods directly upon the Equator, the circle of illumination will reach both poles, and days and nights will be of equal length all over the world.

The two positions B and D are called *equinoxes*, because at these periods, as we have seen, the length of the night is the same all over the world. The Equator is sometimes called the *equinoctial* line, because there the nights are always of equal length. As the circle of illumination is a *great* circle, it always bisects the Equator in whatever position it may be, and hence at the Equator days and nights are always of equal length. As we recede from the Equator, however, they vary more and more, until at the Poles we have "days and nights for half a year." The word *tropics* is derived from a Greek word signifying to turn, because they mark the limits of the sun's northern and southern declination respectively. When the sun has reached its greatest declination it appears stationary for a day or two before it turns back towards the Equator. It is for this reason that the

positions marked A and C are called the *solstices*, a word which means the standing of the sun.

The earth's orbit, in accordance with the first of Kepler's laws, is not a perfect circle, but an ellipse, and the sun occupies one of the foci. That part of the earth's orbit which is nearest the sun is called *perihelion* (περι, near, and ἥλιος, the sun); that part which is farthest distant is called aphelion (ἀπο, from). In winter the earth is actually three million miles nearer to the sun than in summer, but for the reasons already given we do not feel its heat so much. It might, however, be expected that the summers in the southern hemisphere should be hotter than those in the northern hemisphere, and doubtless this would be the case were it not for a compensating cause. There is a large preponderance of water in the southern hemisphere, and the effect of water is to equalize climate—to render the summers less hot and the winters less cold. There is also another circumstance to be taken into account. As the distance between the earth and the sun lessens, the velocity of the earth in its orbit increases, according to Kepler's second law; and as the distance from the autumnal equinox (position B) to the vernal equinox is less than that of the other half of the earth's orbit, the interval between the autumnal and vernal equinox is about eight days shorter than between the vernal and autumnal equinox; and Sir John Herschel shows that during the former and shorter interval the earth, as a whole, receives exactly the same amount of heat from the sun—not more—that it does in the other and longer interval.

Equation of Time.—On a former page we stated that the interval which elapses between the appearance of a star on the meridian and its appearance on the same meridian next day is the time it takes the earth to turn once upon its axis, or 23 hours 56 minutes; this is called a *sidereal day*. A *solar day*, as we have already explained, is about four minutes longer than this. But solar days are not all of equal length; for as the difference between a sidereal day and a solar day is owing to the earth's annual motion, and as this motion is not uniform,

it follows that the solar days will vary in length. As the earth is nearer the sun in winter than in summer, and as it then moves more quickly in its orbit, we should expect the solar days to be rather longer between the autumnal and the vernal equinox than in the other half of the year. But there is another disturbing cause. The sun's apparent path is along the ecliptic, and the ecliptic, we have seen, is inclined to the celestial equator at an angle of $23\frac{1}{2}°$. If, therefore, the earth's motion in its orbit were uniform, the effect of the obliquity of the sun's apparent path would be to cause a difference in the lengths of solar days. For at the solstices the ecliptic is parallel with the Equator, while at the equinoxes it is very oblique. We can see, therefore, that as the sun moves along the ecliptic about a degree every day, the space moved towards the east, as measured on the celestial equator, would be greater at the solstices than at the equinoxes. Hence there are two distinct causes at work to produce irregularities in solar time. Now, it is very desirable that in the ordinary business of life our days should be of uniform length: we take, therefore, the average length of a solar day, and this is exactly twenty-four hours. The difference in the lengths of solar days never exceeds fifty-one seconds, but this difference may go on accumulating for many days together, so that sometimes there is sixteen minutes' difference between solar time as indicated by the sundial and correct Greenwich time. This difference is called the *equation of time;* it can be calculated beforehand for every day in the year, and is often published in almanacs.

There are only four days in the year when solar time and average or *mean solar time*, as it is called, agree. These are April 15, June 14, August 31, and December 24; at other periods of the year the clock is either before or after the sun, and sometimes the difference exceeds sixteen minutes. In order to make use of a table showing the equation of time, we should fix upon some particular day, and note the exact time upon a sundial, then, turning to our table, find out whether the sun is before the clock or after it, and the exact amount. We may

then take out our watch, and put it before the sun or after, as the case may be.

The sidereal day, which is the time used in astronomical clocks, coincides with the time it takes the earth to turn once upon its axis. Practically speaking, this diurnal motion is constant and uniform, though, owing to the retardation produced by the tides, it does lose, according to some mathematicians, about half a minute in a century. We can therefore imagine a time when its rotation was much quicker than it now is; while, on the other hand, there may come a time when the diurnal motion will cease altogether.

Eccentricity of the Earth's Orbit.—We have stated that the earth's orbit is not a perfect circle, and that the amount of its eccentricity is about three million miles. This amount, however, is not constant. Every year it is growing less, and in 23,900 years it will have attained its minimum, that is, the amount of eccentricity will be then only 500,000 miles, and the earth's orbit will be almost a perfect circle. It will then begin to increase gradually until it reaches its maximum, when the difference in distance from the sun between the position of the earth in summer and in winter will be rather over 14,000,000. Now, as there is no doubt that in past ages this maximum amount of eccentricity has been attained more than once, it is important to bear this in mind when we consider the changes of climate that have taken place in geological periods. Looking at the present amount of eccentricity, we should expect that in the southern hemisphere the summers would be very hot and the winters long and cold. This would undoubtedly be the case were it not, as we have already stated, for the present distribution of land and water. Let us suppose, however, that the case were reversed, and that summers in the northern hemisphere took place when the earth was in *perihelion* instead of *aphelion;* then the summers would be very much hotter, and at the same time shorter, while our winters would be long and intensely cold. Now there is no doubt that such a state of things has happened in past geological ages, for,

owing to what is termed the precession of equinoxes, which will be explained in a subsequent chapter, the equinoxes and solstices do not take place on two successive years in precisely the same part of the earth's orbit. The whole four positions partake of a retrograde movement round the earth's orbit, and perform a complete revolution in about 26,000 years.

Let us consider the effect of this when combined with the varying eccentricity of the earth's orbit. In 13,000 years from this time the equinoxes will have moved backward half round the orbit. The vernal equinox will then take place where the autumnal equinox now is, and the summer and winter solstices will have changed places. In other words, the summer of the northern hemisphere will take place when the earth is in perihelion. But this is not all. We can readily conceive that in the course of the vast ages that have preceded us it may have happened that the earth has been in perihelion during the season of the northern summer, when the amount of eccentricity was much greater than it now is. Such a conjuncture took place about 210,000 years ago, when the amount of eccentricity was ten and a half million miles, and Dr Croll thinks that was the date of the *Glacial Period*, for the snow and ice formed during the long and severe winters could scarcely be completely melted during the brief hot summers which followed.

CHAPTER V.

THE MOON: PHASES AND ECLIPSES.

Were we to judge by appearances only, we should conclude that the sun and moon were about the same size. But while, as we have seen, the sun is more than one million times the size of the earth, the earth itself is nearly fifty times the size of the moon. The exact diameter of the moon is 2158 miles, and its average distance from the earth is 238,793 miles. The orbit in which the moon moves is elliptical, the amount of eccentricity being rather more than 13,000 miles. When the moon is nearest the earth it is said to be in *perigee;* when at its greatest distance, in *apogee.* The moon spins round upon its axis in 27 days 7 hours and 43 minutes. It so happens that the period it takes to travel round its orbit is exactly the same: the consequence is, that the same side is always turned towards us. The telescope has made us pretty familiar with this half of the moon's surface, but what the other side is like we can only conjecture.

Strictly speaking, however, we do see a little more than half of the lunar surface. The axis of the moon is inclined 1° 32′ from the perpendicular; consequently we sometimes see the region round one pole, and sometimes the region round the other: this is called the *libration in latitude.* There is also a *libration in longitude,* arising from the fact that the motion of the moon in its orbit is not uniform. We have already mentioned that this orbit is an ellipse, and that the moon is more than 26,000 miles nearer to us at one time than at another. Now, the nearer the moon approaches the earth the quicker it moves. On the other hand, the moon's motion upon its axis is quite uniform; hence it happens that we sometimes see a little round the

western edge, and sometimes a little round the eastern edge. Still, the portion of the lunar surface that is made known to us through libration is very small, and, speaking generally, we may say that with one side of the moon we are totally unacquainted. It has been suggested that our satellite is not a sphere, but is slightly egg-shaped, the thin end being turned towards the earth. So far as we can judge from observation, however, it appears to be a perfect globe, without any trace of polar compression.

Surface of the Moon.—With the naked eye we can see that some parts of the moon's disc are darker than others. These darker spaces were formerly supposed to be seas and oceans, and early astronomers gave them such poetical names as the Sea of Tranquillity, the Sea of Clouds, the Sea of Nectar, the Ocean of Tempests, and the Sea of Serenity. It is now known that there is not a single drop of water upon the moon's surface, and that the dark spaces are smooth plains, very probably the beds of dried up oceans. Through a very good telescope we can see the lunar surface as if it were only 240 miles distant, and when viewed through Mr Newall's large instrument (p. 162) it appears as it would to the naked eye if it were only about 80 miles distant; consequently it has been mapped out with considerable accuracy. We seem to have in the moon an example of a dead globe. It is totally devoid of atmosphere, vapour, or life of any kind. In former ages it was probably torn by fierce volcanic agencies; these fires are now extinct; but in the vast fissures and huge craters which mark the lunar surface we see the tremendous forces that in former times upheaved and cracked the crust of the moon.

The brighter portions of the moon's disc show the position of mountain chains and summits; but these irregularities upon the surface are best seen when we observe the *terminator*, or line which separates the illuminated from the dark portion of the disc. Along this line the mountain peaks are lit up, and the shadows are thrown on the bright surface. From the length of these shadows the heights of more than one thousand summits have been

calculated, and they appear to rival in altitude the loftiest mountains upon our globe. *Dörfel*, which rises from a mountain group near the south pole, is said to reach a height of 26,691 feet; and thirty-nine of the summits measured are higher than Mont Blanc. In considering these elevations we should bear in mind that the diameter of the moon is only about one-fourth of the earth's diameter, and that in bulk the moon is only about one-fiftieth the size of the earth.

Various lunar ranges have been named after mountain chains on the earth's surface; thus we have the Alps, Carpathians, Caucasus, and Apennines. Certain isolated summits have received the names of celebrated men, such as Aristotle, Eratosthenes, Ptolemy, Copernicus, Tycho, and Newton. Several of these summits are extinct volcanoes with enormous craters, which are surrounded by high walls of rock resembling the ramparts of a fortified city. In several cases the cavity of the crater sinks far below the general surface of the moon. In the summit called *Newton* the height of the ramparts from the floor of the crater is nearly 24,000 feet. The size of some of these craters is so great that we can hardly imagine them to be the outlets of a volcano, and they have been termed *walled plains*. One of the most remarkable of these is the circle of *Clavius*, in the southern hemisphere. Its breadth is nearly 150 miles, and it is surrounded by a ring of mountains, several of which exceed 20,000 feet in height. At the bottom of the immense cavity are hundreds of smaller craters, and among them rises a peak 15,000 feet in height. Grimaldi, Shickhard, and other walled plains have almost equal dimensions.

One of the most conspicuous objects in the southern hemisphere of the moon is the summit of *Tycho*, which consists of a mountain group, the centre of which is occupied by a crater fifty miles broad. It is slightly elliptical in form, and surrounded by ramparts which rise 15,000 feet above the surrounding plain. Tycho, like Copernicus, belongs to a system of radiating mountains. Bright *luminous* rays seem to diverge from the centre in all direc-

tions. Some of these rays are visible under all illuminations, others disappear when the sun shines upon them obliquely. They cannot be ridges or mountain spurs, because then they would cast shadows, which they never do. Some have supposed them to be streams of lava, others a kind of moraine left by former glaciers. Tycho, with its crater and accompanying rays, resembles a "star" similar to that produced by a stone thrown against a pane of glass, and some think that the appearance has been caused by enormous pressure from the interior upon the surface of the moon.

Copernicus is situated about 9° north latitude. The crater forms almost a perfect circle, the walls rising about 2350 feet above the surface, while the depth of the crater is 11,300 feet. At the bottom are several eruptive cones; and branching off on all sides of the crater are the luminous rays. In the neighbourhood of Copernicus, as well as in other parts of the lunar surface, *rilles*, or deep trenches with raised sides, are met with. These rilles are sometimes above 1000 miles in length, and their breadth varies from 1000 to 1500 yards. Some of the trenches are perfectly straight, others slightly curved, but still keeping their edges parallel. Some cross each other, and others cross craters, sometimes at great elevations. These rilles or trenches are probably immense cracks in the surface of the moon, caused by some upheaving force.

We have stated that the moon is destitute of any atmosphere: this may be proved in a variety of ways. For example, the moon in its motion round the earth occasionally passes in front of a fixed star, causing what is called an occultation. Now, when this takes place the star disappears at once, and does not appear to linger on the edge of the moon as it would do, owing to refraction, were there any atmosphere. Again, it is seen by means of the telescope that the shadows on the moon's surface are black and well defined; there is no dispersion of light, no half-shade, as there is upon the earth. That the moon did at one time possess an atmosphere there can be little doubt: what has become of it we do not know. But, of course,

when the atmosphere was gone the oceans would evaporate, and the moon's surface would be left dry and barren as it now is. The density of the moon is about three times that of water, or three-fifths the density of the earth.

The moon turns upon its axis in a little more than twenty-seven days. Owing, however, to the earth's motion in its orbit, the time between new moon and new moon is twenty-nine days twelve hours. The lunar days and nights will therefore be nearly fifteen times the length of ours; and as the moon's axis is almost perpendicular to its orbit, there will be no perceptible difference throughout the year in the lengths of day and night, and no variety of seasons. The change, however, from day to night will be very marked, especially as there is no atmosphere to disperse the light and heat or to check radiation. For fifteen consecutive days the sun will continue to shine, and it has been conjectured that the surface will become hotter than boiling water. When the sun sets, all will be plunged at once into profound darkness, as there can be no twilight; and then in the course of the long night the cold will become far more intense than anything we can ever experience on earth. Sometimes, of course, the lunar nights will be lit up by our earth, which will appear in the lunar sky as a moon at least a dozen times larger than the moon appears to us.

Phases of the Moon.—The brightness of the moon is but the reflected light of the sun; one-half of its surface, therefore, is always bright and the other half dark. When the bright side is turned towards us we have full moon; when the dark side is turned towards us the moon is invisible, and we say it is new moon. It follows, then, that the moon will present different appearances to us as its position in its orbit changes. These various appearances are termed phases (*φασις*, an appearance). When the earth, moon, and sun are in conjunction, that is, when the moon is on the same side of the earth as the sun is, and therefore rises and sets with it, the dark side is turned to the earth, and it is therefore invisible; this is *new moon*. As the moon proceeds in her orbit we gradually get a glimpse

of the illuminated side, first as a thin streak of light, which grows broader each evening: the moon is now said to be *crescent.* When the moon has made one-fourth of a revolution we see exactly one-half of the bright side, and our satellite has reached her first quarter. Still advancing in her orbit, the bright side is turned more and more towards us, until at *full moon* we see the whole of it. The moon is now on the opposite side of the earth to the sun, and comes on the meridian at midnight.

In the accompanying figure S represents the sun, E

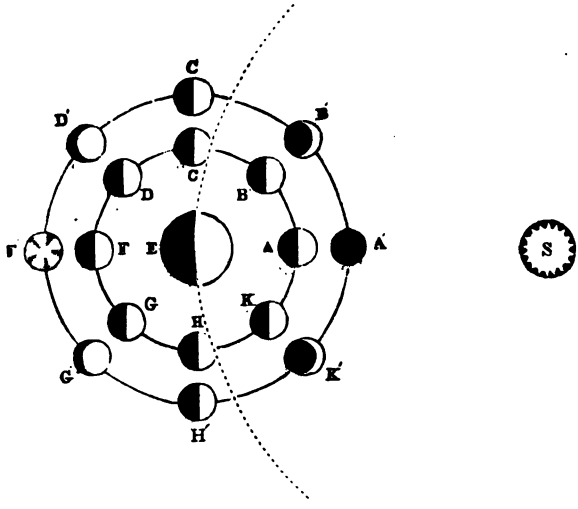


FIG 19.

the earth, and in the inner circle we have the moon in various parts of its orbit, with the bright side always turned to the sun. The outer circle represents the various phases which the moon presents to us during the course of a lunar month.

From new moon to full moon the visible portion of the

lunar disc waxes, or increases in size; it then begins to wane, or diminish, and goes through the same phases as before. When the moon is in her second and third quarters we see more than one-half of the illuminated side, and she is then said to be *gibbous* (L. *gibbus*, hunchbacked). In the last quarter the moon is again crescent in appearance, but now the horns of the crescent are turned towards the west, while in the first quarter they are turned towards the east. This will be easily understood when it is remembered that the bright side of the moon is always turned towards the sun. In the first quarter the moon rises after the sun, and therefore the convex part of the disc is turned to the west; in the last quarter the moon rises before the sun, and the convex part of the disc is towards the east, while the horns point to the west.

The earth reflects the sun's light just as the moon does, and undergoes similar phases. The light which the earth reflects must be very considerable, on account of its size; and near new moon, the earth being almost *full* at the time, the "earth-shine" is reflected back to us, and the dark portion of the moon is sometimes rendered faintly visible. When this takes place the entire outline of the moon is seen, and the "old moon" is said to be in the "new moon's" arms. It used to be thought, without sufficient reason, however, that this appearance was the sign of an approaching storm.

We have said that when it is full moon the moon comes on the meridian at midnight, and is exactly opposite to the sun. It therefore occupies a place in the ecliptic opposite to that occupied by the sun at noon. In winter, therefore, when the declination of the sun is lowest, that of the moon is highest; and thus we get a larger share of moonlight at the time of the year when it is most needed. For a similar reason, about the time of the autumnal equinox the moon rises nearly at the same time for several days together. The full moon which occurs about the end of September, being opposite the sun, is in the vernal equinox, and day after day it will reach a higher declination. Now, in ordinary cases it rises nearly an hour later

each evening, but owing to its increasing declination it rises earlier than usual, just as the sun does after the vernal equinox. The consequence is, that instead of rising an hour later each evening, it appears, as we have said, nearly at the same hour for several evenings together. As these long moonlight evenings are often useful in harvest operations, the full moon which falls near the autumnal equinox is called the "harvest moon."

We have already stated that the moon completes one revolution round the earth in 27 days 7 hours 43 minutes and 11·5 seconds. This is called a *sidereal* month. A *lunar* month, or lunation, that is, the interval from new moon to new moon, is 29 days 12 hours 44 minutes and 2·87 seconds. The reason for this difference is, that while the moon has been going round its orbit the earth has moved some distance onward in its course round the sun, and it takes the moon rather more than two days extra to bring itself again in a line with the earth and the sun. After an interval of nineteen years, new and full moons begin again to fall upon the same days of the months as before, or at most one day before or behind. This period was known to the ancients as the *metonic cycle.*

Eclipses.—When the moon comes directly between the earth and the sun so as to intercept the solar rays, there is an eclipse of the sun; and when the earth comes between the sun and the moon so as to prevent the sunlight from reaching the moon, there is an eclipse of the moon. We might naturally expect that there would be two eclipses every month—one at the new moon and the other at full moon. This would be the case if the moon's orbit were in the same plane as the ecliptic, for then both at full moon and at new moon the sun, the earth, and the moon would be in a line. But the orbit of the moon is inclined to the ecliptic at an angle of 5° 8′ 48″, and hence at full moon and new moon our satellite is often a little above or a little below the plane of the ecliptic, and thus an eclipse is avoided. It is because of this inclination of the moon's orbit that in these latitudes the moon some-

times reaches a greater altitude than the sun ever attains; while, on the other hand, it is sometimes five degrees lower than the lowest declination of the sun.

But the question may arise, How is it that there are ever any eclipses at all? They are owing to the movement of the moon's nodes. The orbit of the moon is, as we have said, inclined to the ecliptic at an angle of rather more than five degrees. The two points where the orbit of the moon cuts the plane of the ecliptic are called *nodes* (L. *nodus*, a knot). The moon in its motion round its orbit, of course, passes those points. There is the ascending node, where it begins to rise above the plane of the ecliptic, and the descending node, where it passes to the south of the ecliptic. Now, these nodes are not stationary; in other words, the moon's orbit revolves upon its axis, always, however, keeping the same inclination, and the nodes complete a circle in about eighteen years. It follows from this that the nodes are sometimes in a direct line with the earth and the sun; and when this is the case there must be an eclipse of the sun at new moon, and an eclipse of the moon at full moon. If the moon be not exactly at a node at the time of new or full moon, we may only get a partial eclipse, the amount, of course, depending upon the distance from the node.

We know that a solid body, when exposed to the light, throws a shadow behind it. The shadow thrown by the earth on the side turned away from the sun is not all of the same density; there is the dark *umbra*, and the *penumbra*, or half-shadow. The penumbra is caused by a portion only of the sun's light being intercepted, the umbra is the result of total eclipse; and hence the penumbra is like a broad fringe, which gradually darkens as the edge of the umbra is approached. When a lunar eclipse takes place, the eastern limb of the moon first enters the penumbra, but the effect on the moon's appearance is not perceptible to the naked eye: this is called the "first contact" with the penumbra. As she proceeds the shade deepens, and at length, when the umbra is reached, the eastern edge is almost invisible, and we have the first con-

tact with the dark shadow. The general outline of the shadow as it encroaches upon the bright surface of the moon is seen to be circular, proving that the earth which casts the shadow is a round body. The moon then passes entirely into the umbra, and there is a total eclipse. It then gradually emerges on the opposite side, and the eclipse is over.

The explanation just given may perhaps be better understood by help of the accompanying diagram, where

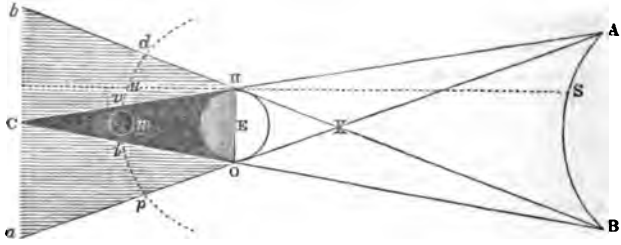


FIG. 20.

A S B represents a portion of the surface of the sun, H E O the earth, and *m* the moon. H C O is the umbra, on each side of which is the penumbra. From the point A proceed the rays A H C and A O *a*, and from the point B proceed the rays B O C and B H *b*. It is evident that the portion of the penumbra C O *a* receives no light from A, while the other portion receives no light from B: indeed, at *n* no rays from the sun's surface between S and B will be received; while in the dark space H C O (the umbra) there is no light at all received directly from the sun.

Even when totally immersed in the umbra, however, the moon is seldom quite obscured: it generally assumes a dull red or copper colour. This is caused by the refraction of the sun's rays in passing through the earth's atmosphere. The light thus bent round the edge of the earth's surface turned to the moon is sufficient to make it faintly visible. But light refracted by our atmosphere is

always more or less tinged with red; hence the peculiar colour seen in a lunar eclipse. The amount of light thus afforded will depend, of course, upon the state of the atmosphere; and sometimes, when the air is laden with clouds, this light is all intercepted and the moon disappears.

As the earth is a smaller body than the sun, the darker part of the shadow, or umbra, is a cone which extends from the earth for a distance of more than 200 times the length of the earth's radius—that is, three or four times the distance of the moon from us. Hence at full moon, when the moon is near the plane of the ecliptic, the moon must pass wholly or partially through the shadow. The cone of shadow cast by the moon, on the other hand, is much smaller, and sometimes during an eclipse of the sun, when the moon is in apogee, the shadow actually does not reach the earth. In that case the moon's disc will not entirely cover the sun, but will leave a narrow ring of light all round it, and we have then what is termed an *annular* eclipse of the sun. This may be seen in the diagram, Fig. 21, where it is plain that an observer at *v* will have part

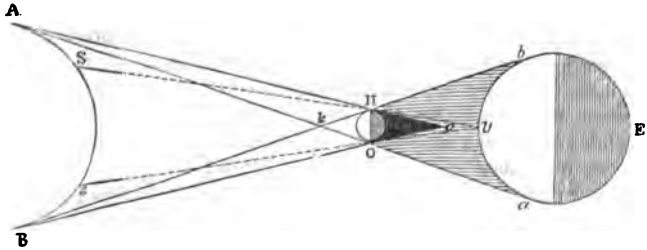


FIG. 21.

only of the sun's surface cut off from view: the parts A S and *s* B will be seen as a luminous ring all round.

Even when the moon's shadow does reach the earth, the diameter of it is comparatively small, not being more, under the most favourable circumstances, than 180 miles, and it is

only within the limits of this dark circle that a total eclipse of the sun is possible. The penumbra, of course, is much larger, but its diameter never exceeds 4900 miles, beyond which there will not be even a partial eclipse. Of course, in consequence of the earth's rotation, the shadow traverses a considerable area of the earth's surface: the limits we have given express the breadth of the zone traversed by the shadow. Solar eclipses of a partial character are not uncommon, but a total solar eclipse at any particular spot is, for the reasons just given, a very rare occurrence. There was no total solar eclipse visible in London between 1140 and 1715; nor has there been one since the latter date, though there have been several annular ones.

Various interesting phenomena are connected with total solar eclipses. We shall, in a future chapter, refer to the bright halo which surrounds the moon at the period of totality and of the red flames or "prominences" which then appear. Another curious phenomenon sometimes observed is known as *Baily's beads.* Just before total obscuration the very narrow crescent of the sun seems broken up into numerous small particles or beads of light. This was first noticed by Mr Francis Baily in 1836. The explanation is, that the outline of the moon, as seen projected upon the sun, is not perfectly circular, but presents a serrated or jagged appearance due to the mountainous character of the moon's surface, and the beadlike appearance is caused by the sunlight shining through the valleys between the peaks. Of course a similar appearance is noticed immediately after totality.

As many as seven eclipses may take place in one year: five solar and two lunar; or four solar and three lunar. The usual number in the course of the year is four; but two only may occur, in which case both will be solar. After an interval of eighteen years and ten or eleven days—according as there have been five or four leap years in the interval—the same series of eclipses, as regards character and extent, begin to occur over again. This is because the moon, after this interval, again returns into the same relative position with regard to the sun and the earth; and the

situation of the nodes in the orbit is then again precisely the same as before. This period of eighteen years was known to the Chaldeans under the name of *saros*. In it there are usually seventy eclipses: forty-one of the sun and twenty-nine of the moon. The *saros* is quite distinct from the *metonic cycle*, and should not be confounded with it.

There is one drawback in the use of the *saros*: it consists of a certain number of days and a fraction over. Consequently a given eclipse will not recur at the same hour of the day, but will be about eight hours later. Hence it may not be visible at the same points of the earth's surface, or, if visible, will not be of precisely the same extent. The moon's motions, however, are now so well understood that astronomers have no necessity to make use of the *saros*. So accurately, indeed, can eclipses now be computed, that not only can their occurrence be predicted long beforehand, but astronomers can reckon back to the exact day on which they happened thousands of years ago. Thus, for instance, the celebrated eclipse foretold by Thales, which put a stop to a battle between the Medes and Lydians, is known by computation to have occurred on the 28th May, B.C. 585.

CHAPTER VI.

Precession—Nutation and Tides.

Precession of Equinoxes.—The fundamental law of gravitation may be stated thus: Every particle of every body attracts every particle of every other body with a force that depends upon the distance of the attracted particle from that which attracts it. The sun, therefore, does not attract the earth as a mass, but as a collection of separate particles. If the earth were a perfect globe this would not matter, but we know that the polar diameter is 26 miles shorter than the equatorial diameter—in other words, there is a protuberance at the Equator. Now, at the solstices this protuberant part of the earth is not in the plane of the ecliptic, and the tendency of the action of the sun and moon is to draw this part of the earth towards the plane of the ecliptic. If the earth were at rest, the effect of this extra attraction upon the parts near the Equator would probably be to alter the inclination of the earth's axis and make it more perpendicular; but this effect is counteracted by the earth's rotation, and the consequence is that the earth's axis describes a peculiar conical motion, resembling that sometimes seen in a top when it is spinning slowly. In the accompanying diagram

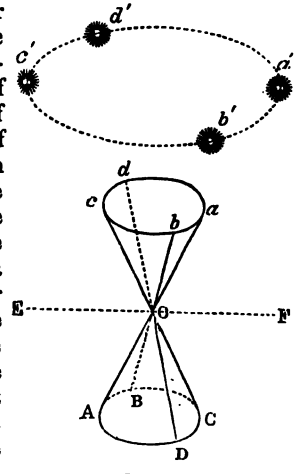


Fig. 22.

(Fig. 22), let A *a*, B *b*, C *c*, D *d* represent the earth's axis, O being the middle point. The earth's axis does not always remain in the same position, A *a*, but turns on its centre O, passing from A *a* to B *b*, etc., the Poles describing the circles A B C D, *a b c d*; thus each half of the diameter describes a cone, but the inclination to the ecliptic does not alter.

Now, supposing that when the earth's axis is pointing in the direction A *a* the seasons take place in the positions represented in the diagram on p. 195, then, when it has changed round so as to point in the direction of C *c*, the positions will be reversed. It will be seen from this that one effect of this conical movement of the earth's axis is to cause that after a certain interval winter will take place in that part of the earth's orbit which is now the summer solstice; and this being so, the vernal equinox must then take place where the autumnal equinox now is. In other words, there will have been a slow retrograde motion of the equinoxes along the ecliptic. From observation it is found that this motion amounts to 50·21″ annually, so that since the time of Hipparchus (B.C. 150) the equinoxes have moved westward about thirty degrees, and they will complete a revolution and return to their former positions in about 26,000 years.

It was stated in a former chapter that the R. A. of all stars was measured from the first point of Aries, and that this point is at the intersection of the ecliptic with the celestial equator, or the place where the sun is at the vernal equinox. Now, as the equinoxes have a slow retrograde motion, the consequence is that the R. A. of all stars is slightly increased every year. In the time of Hipparchus, as we have already stated, the vernal equinox took place in the constellation called Aries, and hence the term "first point of Aries." At the present time that constellation has a R. A. of about thirty degrees, and the first point of Aries is in Pisces. Another result of the precession of the equinoxes is that the north polar distances of stars change from year to year. The pole of the heavens, or the celestial pole, as it is sometimes called, is that point

among the stars to which the earth's axis points. But this point, as we have seen, is not fixed, but describes a circle round what is termed the pole of the ecliptic, which is a line drawn perpendicular to the plane of the ecliptic (see Fig. 22). Our present Pole-star is about one degree and a half from the celestial pole, but it did not always occupy its present position. About 4000 years ago the brightest star in the constellation of the Dragon was nearest the Pole, and in about 12,000 years' time it is probable that Vega, in the constellation of the Lyre, will be the Pole-star. Of course, as the Pole changes its position the north polar distance of all stars will be altered.

It has been stated that the amount of precession is about fifty seconds annually. At this rate the equinoxes would make a complete revolution of the ecliptic in 25,898 years; but this cycle is shortened owing to what is called the *revolution of the apsides.* The line of apsides is the major diameter of the earth's orbit, or the line which joins the aphelion and perihelion points. Owing to the attraction of the other planets, especially Jupiter and Saturn, the aphelion and perihelion points shift about eleven seconds annually; and as this movement is in the contrary direction to the movement of the equinoxes, the result is that the seasons make a complete revolution in 21,000 years instead of 26,000; and hence in 10,500 years from this time the present astronomical state of things will be reversed, so that winter will occur in our hemisphere in aphelion, and summer in perihelion.

It will be evident from what has been said that from one vernal equinox to the next one the earth has not made a complete circuit of its orbit, as the equinox has moved backward the space of fifty seconds to meet it. Hence there is a difference between what is called a *tropical* year—from equinox to equinox—and a *sidereal* year, that is, a complete revolution round the sun: the latter is 20 minutes 20 seconds longer than the other. But, in the meantime, while the earth has been going round its orbit the line of apsides has been slowly shifting eastward,

so that although the earth may now be in the same position among the stars that it was when the vernal equinox took place the previous year, it will not have reached precisely the same part of the orbit. To do so it must move a further distance of 11·8″, and it requires 4 minutes 40 seconds to do this; this period is called the *anomalistic* year. A tropical year is 365 days 5 hours 48 minutes 49 seconds in length; a sidereal year is 365 days 6 hours 9 minutes 9 seconds in length; an anomalistic year is 365 days 6 hours 13 minutes 49 seconds in length.

Nutation.—The circle which the celestial pole describes round the pole of the ecliptic is not a perfect one, but is waved or undulating, as represented in the adjacent figure (Fig. 23). This oscillatory motion of the pole is termed *Nutation* (L. *nutare*, to nod), being a sort of nodding motion of the earth's axis. This wavy or nodding motion is caused by the moon. It was mentioned in the last chapter that the moon's orbit was inclined to the plane of the ecliptic at an angle of 5½ degrees, and that the nodes make a complete revolution in nineteen years. The consequence is that for nearly half that interval the moon's orbit is inclined to the ecliptic in the same way as the earth's Equator, though not to the same degree; and during nearly the other half of the time the moon's orbit is inclined to the ecliptic in a direction opposite to that of the Equator. In the first case the effect of the moon in causing precession is comparatively small; in the second case it is very considerable. Hence there is an irregularity in the motion of the earth's axis every nineteen years, and this causes the wavy line or nutation.

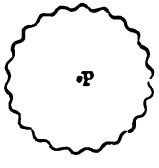


FIG. 23.

Now, from the amount of lunar nutation we can determine what force the moon exerts upon the protuberant parts of the earth, and therefore what share it has in causing the precession of equinoxes; and it has been found that the effect produced by the moon is to that pro-

duced by the sun as 5 to 2. This may appear astonishing at first when we remember that the moon's mass is not a twenty-millioneth part of the sun's; and although it is four hundred times nearer, still that does not explain the difficulty. For, taking distance into account, the absolute attraction of the sun is at least one hundred and twenty times that of the moon. But the effect in forming precession does not depend upon the absolute attraction of the sun and moon, but upon the difference of attraction exerted upon different parts of the earth, as upon the surface and centre, for example. The attraction which the moon exerts upon the surface of the earth is very different from that exerted upon its centre, for 4000 miles is a considerable fraction of 240,000. But 4000 bears a small proportion to 90,000,000, and hence the difference of the sun's attraction upon the surface and centre is not so marked. The same explanation applies to the greater influence which the moon exerts in forming the tides.

The Tides.—Tides are caused by the attraction of the sun and moon, but chiefly by the moon. It has been already remarked that, according to the law of gravitation, the sun and moon attract the earth not as a whole, but as a number of separate particles. In the solid mass of the earth the power of cohesion resists the separation of the particles, but in fluids and gases the particles move easily over each other, and thus both the air and the ocean are drawn up from the solid portion of the earth in a kind of ridge or undulation.

It will simplify the explanation of the cause of tides if we first suppose the earth to be entirely covered with

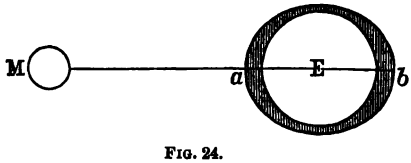


FIG. 24.

water. Let E represent the earth, and M the moon. The moon, M, will attract the water at *a* more than the

solid part of the earth. Thus on the side next the moon the waters will be heaped up, and a tide will be formed. And as each place on the earth's surface is brought successively under the influence of the moon in the course of twenty-four hours, we might expect that there would be one tide each day everywhere. But there are two tides daily, and for this reason. Referring to our diagram, we see that the moon attracts the water at *a* more than the solid earth itself; but it also attracts the solid earth more than the water at *b*, because the centre of the earth is nearer to the moon than *b* is. Hence the earth is drawn away from *b*, and the water, being left behind, appears bulged up on that side. Thus we see that two tides are formed at the same time on opposite sides of the earth. The two tidal waves thus produced would travel from east to west, moving at the Equator at the rate of about a thousand miles an hour if the earth were, as we supposed, entirely covered with water. But the distribution of land materially affects the course of these tidal undulations. It is only where there is a large expanse of water that the wave can be properly developed; and as the largest expanse upon the globe is in the South Pacific, many writers think that it is only in that ocean that a real tide is produced by the direct action of the moon, and that the tides felt in other parts of the world are merely *derived* waves, similar in character to the ripple in a pond caused when the water is disturbed.

Tidal Wave.—Suppose, then, a real tide were formed in the South Pacific, a series of tidal waves would be produced. One vast ridge of water, forming the crest of a wave which reaches to the bottom of the sea, would move westward towards Tasmania. Twelve hours later this ridge would stretch across the Indian Ocean, one extremity reaching Cape Comorin, the other being not far from the Cape of Good Hope. The undulation now enters the Atlantic, and another interval of twelve hours brings one portion of the wave to Newfoundland and another to Cape Blanco, on the west coast of Africa. The direction of the coast of North America deflects the wave eastward

across the Atlantic, and in four hours it reaches the mouth of the English Channel. Here the tidal wave divides: one branch creeps slowly up the English Channel, and in eight hours reaches the mouth of the Thames. A second proceeds up St George's Channel and the Irish Sea, and in six hours arrives at Solway Firth. A third travels along the west coasts of Ireland and Scotland, passes through Pentland Firth, turns southward, and reaches Aberdeen in eight hours. It now proceeds slowly to the south, bringing high water to different ports on the east coast in succession, and when in the neighbourhood of the Wash meets the wave which travelled up the Channel to the mouth of the Thames.

The tidal wave is not a current, like the Gulf Stream, otherwise a vessel on the crest of such a wave might cross the Atlantic in four hours. It is merely a rise and fall of the water; the *wave* travels, the water does not. The movement has been compared to the waving of the ears of corn in a field: the corn-stalks remain fixed in the ground, while the wave travels from one side of the field to the other. Very similar to the tidal wave are the undulations caused by a steamer when passing up a large river like the Thames. The steamboat waves may cause a small boat to rock, but they do not drift it towards the shore. It is only in shallow water that such movements become waves of *translation*. In that case the bottom of the wave is retarded by friction, and the top, advancing more rapidly, rolls forward on to the beach. It is only when the tidal wave reaches the shallow water round our coasts that it loses its proper character and assumes the nature of a current. The Astronomer Royal, while admitting that the tides round our shores are derived waves, doubts whether the oscillations commenced in the South Pacific would be felt so far away from their source, and thinks it more probable that the disturbance to which our tides are due originates in some part of the Atlantic basin.

It has been found that the deeper the ocean the more rapidly travels the tidal wave. We have seen that it crosses the Atlantic in four hours, while it takes eight to

travel up the English Channel. We may thus approximate to the depths of the ocean in different parts by observing the rate at which the tidal wave travels. In mid-ocean the rise of the tide is very slight: thus at St Helena, for example, it rarely exceeds three feet. In narrow, shallow channels the wave travels slowly, and the waters accumulate, causing very high tides. At the mouth of the Thames the rise of the spring tides is eighteen feet; at the mouth of the Bristol Channel, thirty-six feet; at Chepstow, on the Wye, they reach fifty, sixty, and even seventy feet. In the Bay of St Malo, on the north coast of France, the tide sometimes rises fifty feet, while in the Bay of Fundy, in Nova Scotia, it has been known to reach seventy-five feet. Often at the mouths of rivers the tidal wave forms what is called a *bore*. This is caused when either the shallowness of the water, the narrowness of the channel, or the opposing current of the river retards the first portion of the tide, and the succeeding waters accumulate perpendicularly. In the mouth of the Severn the bore rises nine feet, and at the mouth of the Amazon it reaches twelve feet.

As the tidal wave, under ordinary circumstances, always travels at the same rate, when once the time at which high water takes place is known all future tides may be calculated. The exact time at which high water takes place at any port after new or full moon is called the *establishment* of the port. The tides do not succeed each other, however, at intervals of twelve hours, as might be expected; for while the earth is making a revolution on its axis the moon is moving in its orbit, and the earth makes rather more than one revolution before the moon is again on the meridian. This completes a *lunar day*, which is 24 hours 50 minutes, and hence the tides follow each other at intervals of 12 hours and 25 minutes.

We have hitherto spoken as if the moon were the sole agent in forming the tides; but the sun also has considerable influence, though not to the same extent. This is well illustrated in the phenomena of spring and neap tides. When the sun and moon are in conjunction, as at new

moon, or in opposition, as at full moon, then they both contribute to form the same tides, and high *spring tides* are the result. When the moon is in her quarters her influence is exerted at right angles to the direction of the sun's attraction, and therefore the two luminaries are counteracting each other, and *neap tides* are the result. These low tides, in fact, represent the effect of the moon's attraction, minus the effect produced by the sun. The reason why the sun exerts less influence in forming the tides than the moon does has been explained in speaking of the precession of equinoxes; the effect does not depend upon the absolute attraction exerted by either luminary, but upon the difference of their attraction upon different parts. And this differential effect on the part of the moon is about treble that of the sun, or, more exactly, as 5 : 2.

Besides the monthly variation of spring and neap tides, we have occasionally very high or very low tides arising from other causes. Thus if the spring tides occur when the moon is in perigree, they will be higher than usual. For a similar reason it is noticed that the tides are higher during the winter of the northern hemisphere, when the earth is nearer the sun. The wind, also, has an important effect upon the height of tides. It has been noticed in the Thames that the most disastrous overflows have occurred when a strong south-west wind has suddenly changed to the north-west. The reason being that a south-west wind brings an increased quantity of water across the Atlantic to the northern parts of the North Sea, and a sudden change in the wind brings the whole of this water to the southward. On the other hand, the effect of a south-western gale alone is to depress the height of the water at the mouth of the Thames.

As the general tendency of the tidal wave in the great oceans is to move westward, following the moon, while the motion of the earth on its axis is from west to east, it has been surmised that the tides must eventually affect the rate at which the earth revolves on its axis. We mentioned in the last chapter that the exact date at which ancient eclipses took place could be calculated by astrono-

mers with great accuracy. It appeared at one time as if the motion of the moon had undergone an acceleration during the last twenty-five centuries. Laplace partly accounted for this, but not altogether; and now it is generally admitted that the discrepancy still existing is owing to a retardation of the earth's rotation by tidal friction. Sir William Thomson, in a paper read before the British Association at the Glasgow meeting in 1876, thus speaks on the subject: "The conclusion is that since March 19, 721 B.C., a day on which an eclipse of the moon was seen in Babylon, commencing 'when one hour after her rising was fully past,' the earth has lost rather more than $\frac{1}{5,000,000}$ of her rotational velocity, or, as a time-keeper, is going slower by eleven and a half seconds per annum now than then. According to this rate of retardation, if uniform, the earth at the end of a century would, as a time-keeper, be found twenty-two seconds behind a perfect clock rated and set to agree with her at the beginning of the century."—*Nature*, No. 359.

By comparing the spring and neap tides we can ascertain the relative densities of the moon and sun. The spring tide is the effect produced by the sum of the attractions of the sun and moon; the neap tide is the effect produced by their difference. It is easy, therefore, to ascertain how much is due to the moon alone. Now, as force of gravitation depends upon the distance and mass of the attracting body, and as we know the distance, we can easily obtain the mass. And after careful calculation it is found that the moon's mass is about $\frac{1}{80}$ of that of the earth. But as the earth is only forty-nine times as large, but eighty times heavier, it follows that the moon is less dense than the earth: the exact proportion is as ·63 to 1. This result obtained from the work done by the moon in forming the tides agrees with the result obtained by taking into account the influence of the moon in causing the precession of equinoxes. The density of the sun is only about one-fourth that of the earth.

By a similar process of reasoning, that is, by noticing the effect of the various planets and their satellites upon

each other, we have been able to compute their densities. Indeed, the planet Neptune was discovered in this way. Every body in the solar system affects the motions of every other body; for the law of gravitation is that every particle of matter attracts every other particle. After Uranus had been discovered some time, it was found that, after taking every known cause into account, there was still something affecting his motion. Mr Adams at Cambridge, and M. Leverrier in France, set to work to study the question, and both came to a conclusion, quite independent of each other, that there was a planet somewhere beyond the orbit of Uranus, and not only so, but they indicated the exact spot in the heavens where it should be looked for. Leverrier wrote to Berlin stating where, according to his calculation, it was to be found. Dr Galle looked for it, and it was found the same evening very near the spot indicated by both the astronomers.

CHAPTER VII.

THE SUN: SUN-SPOTS AND THE WEATHER.

We have already stated that the diameter of the sun exceeds 850,000 miles, and that the sun itself is 1,275,000 times the size of the earth. It possesses, however, only about one-fourth the earth's density, and this is doubtless owing to the intense heat of the mass. The amount of heat and light which the sun radiates is enormous. It is said to give out 146 times as much light as would be produced by a limelight of its own size; and the heat thrown out is as great as that which would be produced by burning six tons of coal each hour upon every square yard of its surface. The sun cannot continue for ever radiating heat and light unless it be replenished, any more than a fire can continue to burn without the addition of fuel. Hence there may come a time when the sun's heat and light will be exhausted, and when it "will roll, a cold, black ball, through infinite space."

So far as our observations go, the sun appears to be a perfect sphere, and not flattened at the poles like the earth and other planets. It revolves upon its axis in about twenty-five days, but the exact time has not been determined. The sun's rotation has been ascertained by noticing the movements of sun-spots across its disc, but it has recently been discovered that these spots have a movement of their own, called their *proper motion*, and that this movement is not uniform. Near the equator the spots travel more quickly than at a distance from it. The movement of the sun's spots also shows us that the axis of the sun is not perpendicular to the plane of the ecliptic, but inclined to it at an angle of about 83°. The inclination is towards the part of our orbit where the earth passes at the

autumnal equinox. If a sun-spot be on the solar equator, it will appear to cross the sun in a straight line slanting from north-east to south-west, when viewed either from the summer or winter solstice; when at the equinoxes the spot will appear to describe curves, the convex portion of the curve being towards the north at the vernal equinox, and towards the south at the autumnal equinox.

Surface of the Sun.—The bright surface of the sun which we see with the naked eye has been termed the *photosphere*, and is supposed to consist of metals and other substances in an incandescent state. In the bright photosphere are the dark cavities called sun-spots. Some of these are from 30,000 to 40,000 miles in diameter, and chains of them are often seen extending 100,000 miles or more from end to end, generally parallel to the sun's equator. When viewed through a telescope, three distinct shades may be noticed; first, the *penumbra*, or half-shade, which surrounds the margin; secondly, the *umbra*, or darker shade; and thirdly, the *nucleus*, which appears quite black. It was once thought that this nucleus was the opaque body of the sun itself, which was surrounded by a glowing atmosphere whence we derive our light and heat. This opinion is not now generally held. The sun-spots are no doubt cavities or hollows in the photosphere, and the shades represent different depths. The nucleus is only dark by comparison, for it has been found that the darker parts of the spots yield a spectrum similar to that of the brighter portions of the sun's surface, only fainter; and this may be due either to the absorption of a greater thickness of atmosphere, as the spots are depressions in the photosphere, or to this cloudy envelope being less brilliant at a great depth.

In the neighbourhood of the sun-spots, especially when they are approaching the edge of the solar disc, are often seen very bright streaks or ridges of light. These are termed *faculæ* (torches), and are the most brilliant parts of the solar surface. They are of all magnitudes, sometimes 40,000 miles in length and from 1000 to 4000 miles broad. As such ridges often surround a sun-spot, it is not

improbable that they may be elevations in the photosphere produced by the same convulsions as those which cause the spots themselves. Another appearance connected with the sun-spots are "willow-leaves," or elongated oval masses of unequal brightness, which occasionally fringe the edge of the penumbra, and sometimes detach themselves from it. Apart from the spots and faculæ, the solar surface is not all of the same brilliancy. When carefully examined, it presents a mottled appearance. Viewed through a large telescope, the surface is seen to be covered with luminous prominences presenting almost every variety of form. These masses are said to resemble "rice-grains," or "granules," and between the granules are numbers of dark dots called "pores" or "punctulations." These pores are probably of the same nature as sun-spots, but on a smaller scale.

Such are some of the appearances presented by the surface of the sun when examined through a powerful telescope: a solar eclipse brings new features into view. When the eclipse has nearly reached totality, the dark moon which now covers the ordinary surface of the sun is seen surrounded by a bright halo of silver light. This is called the *corona*, and is supposed to be the sun's atmosphere. When the totality is complete, certain pink and red flames of curious shapes are observed close to the edge of the moon, and therefore within the corona. Sometimes they appear as if attached to the edge of the moon; at other times they are quite separated, suspended, as it were, in the corona. It is proved that these red flames or "prominences" belong to the sun, as those at first visible on the eastern side are gradually obscured by the moon in its passage across the solar disc, while those on the western side are becoming more visible. The height of some of these flames above the sun's surface has been estimated at 90,000 miles, and they are composed of incandescent hydrogen gas and metallic vapours, one of which is probably sodium.

The region in which the red flames are found has been termed the *chromosphere*; so that, so far as is known at present, there would seem to be three distinct regions of

the sun with which we are more or less acquainted: the luminous surface, or photosphere; the chromosphere, immediately outside; and the coronal atmosphere surrounding all. Besides these three regions, however, there is between the photosphere and the base of the chromosphere a comparatively thin layer,—called "the reversing layer,"—which is highly interesting in connexion with spectrum analysis.

Sun-spots.—Scientific men are now agreed that the sun-spots are cavities in the photosphere, caused by violent storms similar to the cyclones which prevail in the tropics. It has been noticed that the northern hemisphere of the sun is more prolific in spots than the southern hemisphere, and that they are most numerous in the region that extends from 8° to 28° north of the solar equator. They seem to be caused by up-rushes of incandescent hydrogen gas, which, after ascending high in the coronal atmosphere, become gradually cooled and then sink down again into the yielding surface of the photosphere. These upward and downward currents move with inconceivable velocity —sometimes at the rate of 30 or 40 miles in a second. These up-rushes of glowing gas are identical with the red flames or prominences seen during an eclipse, and Professor Balfour Stewart thinks that these red flames are identical with the faculæ which are always seen in the neighbourhood of sun-spots: "The faculæ are seen projected against the surface of the sun, but these red flames are seen in elevation against the sky beyond." *

The duration of the sun-spots is as various as their size. Some last only a few hours, others continue for several months; but while they exist they are undergoing continual change. It is now generally admitted that there is a certain periodicity in their appearance. There is a minimum period when none are seen for weeks together, and a maximum period when they are more numerous than at any other time. The interval between two maximum or two minimum periods is about eleven years. There is reason to suppose that these periodic changes are due in

* *Manchester Science Lectures:* Fourth series.

some way to the influence of the planets, but how this influence acts can only be conjectured. Some have thought that the attraction of the planets causes a kind of solar tide, but the convulsions connected with the sun-spots are rather of the nature of storms than of tides. The sun, in fact, appears to be in a state of ebullition, and the up-rushes and down-rushes "are the same sort of currents which you get in a tea-kettle."* Whatever may be the causes of the solar changes, however, one thing seems certain, that they have an important influence upon the climatic conditions of the earth.

Dr W. W. Hunter has pointed out a connexion between the cycle of sun-spots and the amount of rainfall in India. During his investigations into the rainfall of Madras he noticed that between the years 1810 and 1867 six years of minimum sun-spots had occurred, and that for all practical purposes the year of the last great Indian famine (1877) might be considered the seventh. He found also that six great famines had occurred in India during the same period (1810–1877), and that five of these were caused by years of drought coincident with, or adjoining to, the periods of minimum sun-spots. He further showed that the rainfall at Madras passed through a regular cycle of greater or less abundance corresponding with the eleven years' cycle of solar changes. Mr Meldrum, a meteorologist and observer in the Mauritius, was at the trouble of collecting all the logs of vessels that crossed the Indian Ocean in a period of twenty or thirty years, and he found that the time of maximum sun-spots coincided with the time when cyclones were most numerous in the Indian Ocean.

There appears to be a difference of opinion, among those who have given attention to this subject, whether the light and heat which we obtain from the sun is greater or less during the maximum sun-spot period. At the first thought we should naturally conclude that the spots on the solar surface would diminish the light and heat which we obtain from the sun. This was at one time Professor

* Lockyer.

Balfour Stewart's opinion, and he thought also that at these periods we obtained less of those actinic or chemical rays upon which vegetation so much depends. It has been noticed, he tells us, that what are termed "good wine years" on the Continent correspond with years of minimum sun-spots. He is now disposed, however, to believe, though as yet there is no positive proof of the fact, that we actually receive a greater amount of light and heat during the sun-spot period. For, as we have seen, this is a period of great solar activity, and the upward currents of hydrogen are "incandescent to the last degree."

Meteorologists have long been aware of certain waves of heat and cold which sweep through the atmosphere and materially influence the climate of the globe. Professor Piazzi Smyth, the Astronomer Royal of Scotland, traces a connexion between these waves and the solar cycles. The minimum sun-spot period was past in 1880, and the summer of 1879 was exceptionally cold. Several large sun-spots were observed in October 1879, and Professor Piazzi Smyth thinks that a warm wave then set in.

Terrestrial Magnetism. — But whatever diversity of opinion may exist as to the amount of heat which we receive from the sun at different periods of the solar cycle, upon one thing every one is agreed, that the maximum sun-spot period coincides with a period of magnetic storms and brilliant auroræ. We have in a former chapter (p. 17) explained briefly the nature of magnetism, and shown its connexion with electricity. The force and direction of the magnetic currents which circulate through the earth are indicated by the declination and dipping needles. In the mariner's compass the needle is so fixed on the card that it only shows declination; but if a magnetic needle were suspended by a thread so as to be allowed to move freely in a vertical direction, it would, in these latitudes, dip towards the north. The north end of the dipping-needle dips below the horizon in the northern hemisphere, the south end in the southern hemisphere. But there is a line encircling the earth where the needle always remains horizontal. This is called the *magnetic equator*, and it cuts the

geographical equator a little to the east of the meridian of Greenwich, and again at 170° E., and it never deviates more than 12° or 15° from it. As we recede from the magnetic equator the needle dips more and more, until at the magnetic poles it points perpendicularly. These do not coincide with the geographical poles. The *North Magnetic Pole* is at a point 70° north and 97° west; the *South Magnetic Pole* is supposed to be in lat. 75° 5′ south and long. 154° 8′ east. Sir John Ross, who was sent out to determine the exact spot, was prevented from accomplishing his purpose by a great barrier of ice; but he fixed upon the spot we have indicated by calculation.

In some places the declination-needle used in the mariner's compass points due north, in other parts it deviates to the east or west more or less. In England the magnet points more than 18° to the west of north; this is called the needle's *declination*. In the north of Greenland the needle points due west; while still farther to the north-west the north end of the needle points due south. This is, of course, because the needle has been carried beyond the magnetic pole. If, when the needle is at rest pointing in a certain direction, we alter the direction in which it points, it will return to its original position with more or less energy. This energy, or magnetic force, as it is termed, is indicated by the number of vibrations it makes in a given time, and is not always the same. There are four foci of greatest intensity, two in the northern and two in the southern hemisphere. There is also a line of minimum intensity, called the *dynamic equator*. Besides the circles, poles, and foci to which we have just referred, there are other lines on a magnetic chart which may be briefly explained; these are termed isoclinal, isogonal, and isodynamic lines. *Isoclinal* lines are those which pass through places where the inclination or dip of the needle is the same. *Isogonal* lines are those which pass through places where the declination of the needle is the same. *Isodynamic* lines denote equal intensity.

The three great magnetic elements—the total force, the inclination, and the declination — are subject to daily

changes, to annual variations according to the position of the sun in the ecliptic, and also to great disturbances called magnetic storms. All these changes have clearly some connexion with the sun, but the variation of the declination-needle has not yet been satisfactorily explained.

In England, at present, the declination is about 18½° west, but this was not always the case. In 1580 the needle at London had an eastern declination of about 11½°; in 1663 its direction coincided with the astronomical meridian; since then it has moved westward, but reached its maximum western declination in 1818, and is now again moving eastward, so that in time its declination will again be zero.

But whatever may be the cause of this irregularity in declination, there is no doubt about there being a connexion between sun-spots and magnetic storms. From records which are kept at Kew Observatory, it appears that in those years in which there have been the greatest number of sun-spots there have also been the most frequent magnetic disturbances. A striking illustration of this connexion between solar and terrestrial phenomena was afforded in 1859. In September of that year, while Mr Carrington was observing the spots on the sun, he suddenly noticed a bright spot break out on the solar surface. The whole time from its appearance to its disappearance did not exceed five minutes; but on inquiry being made at Kew, it was found that the magnetic needles there had been violently agitated at that very time. Strong electric currents were also noticed in the telegraph wires in North America as well as Europe, and a telegraphic apparatus in Norway was set on fire. Beautiful auroræ were seen in both hemispheres, and the agitation in the magnetic currents lasted several days.

The *aurora* is often seen in this country on a clear winter's night in the northern part of the sky. It is generally of a ruddy appearance, with streamers of coloured light shooting out in all directions. In the Polar regions it is remarkably brilliant. The following description was written by Lieutenant Howgaard, who was on board the *Vega* in its memorable voyage round the Asiatic continent

(p. 110). The display was witnessed in the month of September, when the vessel was off Cape Ouman:—"About ten o'clock at night a flame began to ascend from the northern horizon, its centre being due north. It was followed by several others, which slowly approached the zenith, losing gradually something of their intensity, which, however, they recovered when they disappeared towards the southern horizon. The flames were perfectly white, and the heavens were soon covered with flaming arches, which presented a splendid appearance against the dark sky, in which the stars shone brilliantly. Towards midnight the phenomena became more disturbed. In a large broad band which passed through the zenith, the light, of all the hues of the rainbow, waved forwards and backwards, without its being possible to say whether the light-waves came from east or west; but towards the east the flame was especially flickering, and here a flaming torch rose above the horizon, from which immense flames of light issued and again returned. The band suddenly became weaker, while the torch, flaming wildly, became larger, and from the zenith a number of light yellow rays shot out in all directions. This lasted about a quarter of an hour, when the former arches reappeared, gradually disappearing towards the North Pole. No sound was heard while this startling phenomenon was observed."

It is generally admitted that the aurora is connected in some way with electric or magnetic action, but its precise origin is still doubtful. Perhaps the most generally received opinion is that the phenomenon is due to currents of electricity passing through the upper regions of the air from one magnetic pole to the other. In favour of this view it is to be said that the auroral displays are most intense in a region surrounding the magnetic pole, and that gradually as we proceed northward to the geographical pole, or southward towards the equator, the displays are less brilliant, and in the northern hemisphere they are seldom seen south of middle latitudes. Again, the rays or streamers which are seen in the aurora are always parallel with the dipping-needle, and this is pro-

bably one reason why auroræ are seen to greater advantage in high latitudes, for as we approach the equator the displays, even if they took place, would be so high above us as to be quite invisible. One difficulty in connexion with this theory is the great height of the aurora. From observations of some prominent streamers made at distant stations it has been concluded that it extends to the height of 400 or 500 miles. But the evidence of shooting-stars seems to fix the limit of the atmosphere at about 100 miles. If it extends beyond this distance it must be exceedingly rare, and, it is thought, would be incapable of conducting electricity long before it reached its greatest height. In reply to this it has been urged that a common laboratory experiment shows that an electric discharge, invisible under ordinary circumstances, becomes brilliant when the air is much rarefied, though it dies away if the air be further exhausted. It has also been suggested that the electrical discharge from the magnetic pole may possibly carry a certain amount of air along with it into the higher regions. The spectrum of the aurora is far from being uniform, and throws little or no light upon its origin.

CHAPTER VIII.

THE SOLAR SYSTEM.

It has already been stated that other globes besides the earth revolve round the sun. Some are larger than the earth, some less; some are nearer to the sun, others more remote. Several have satellites or moons attending them, and in some the presence of an atmosphere has been detected. Besides the planets, there are other bodies more erratic in their movements, which also revolve round the central luminary; all these planets, satellites, asteroids, comets, and aerolites are included in what we term the *solar system.*

We have already pointed out how a knowledge of Kepler's third law enables us to determine the distance of the sun; and, that distance being ascertained, the same law enables us to fix the distances of the various planets, for their periodic times may be ascertained by observation, and the law states the relation which exists between the distances and the periodic times. The distance of a planet, again, enables us to ascertain its size, and a comparison of its size with its power of attraction leads to a knowledge of its density. The planets which are nearer to the sun than the earth is, are Mercury and Venus; while Mars, Jupiter, Saturn, Uranus, and Neptune are more remote. A remarkable law respecting the various distances of the planets from the sun was announced by a German astronomer named Bode, who died in 1826. The law, if we may so term it, is not strictly accurate in all cases, but it is useful as an aid to the memory. It may be stated thus:—

Taking the distance of Mercury as	4 +	0	=	4
The distance of Venus will be	4 +	(1×3)	=	7

The distance of Earth		$4 + (2 \times 3) =$	10
"	Mars	$4 + (4 \times 3) =$	16
"	Ceres (asteroid)	$4 + (8 \times 3) =$	28
"	Jupiter	$4 + (16 \times 3) =$	52
"	Saturn	$4 + (32 \times 3) =$	100
"	Uranus	$4 + (64 \times 3) =$	196
"	Neptune	$4 + (128 \times 3) =$	388

Thus if we take the mean distance of Mercury as 36 million miles, the distance of Venus will be 63 millions; of the earth, 90 millions; Mars, 144 millions; Ceres, 252 millions; Jupiter, 468 millions; Saturn, 900 millions; Uranus, 1764 millions; Neptune, 3492 million miles. This singular relation between the various distances was known to Kepler, but as it was first published by Bode, it bears his name. At the time of its announcement (1778) neither Uranus, Neptune, nor any of the asteroids had been discovered; and hence there was a gap in the series between Mars and Jupiter. It was suggested, therefore, that there might be a planet somewhere in this wide interval that had hitherto escaped detection. Three years later Sir William Herschel discovered Uranus, and as it was found to conform to the law it was decided to make an organized search for the planet necessary to complete the series. A society of astronomers was formed; the zodiac was divided into twenty-four zones, and each zone was confided to a member of the society. At length, on the first day of the present century, the small planet *Ceres* was discovered by Professor Piazzi, and was found to occupy the required position. Thus the law was found to hold good in a remarkable way in the case of all the planets from Mercury to Uranus. The planet Neptune, however, discovered in 1846, completely violates it, as its mean distance from the sun is only 2746 million miles.

Asteroids.—The discovery of Ceres was shortly followed by the discovery of other small planets in the same region, and at present about two hundred and forty of these *asteroids*, as they have been termed, are known, and every year adds to their number. The largest, Ceres and Vesta, have each a diameter of about 230 miles, while

many of the smaller ones are less than fifty miles in diameter. They move in orbits which, in some cases, are very elliptical, but taken together they occupy a zone 240 million miles in width. The larger planets move in orbits that nearly coincide with the plane of the ecliptic, but the orbits of the asteroids make a very considerable angle with it. Pallas is the most extreme, the inclination of its orbit being 34° 42′. Some have supposed the asteroids to be the fragments of a planet that has exploded, or been broken by concussion, but this opinion is not very general. The total mass of all the asteroids taken together would not form a planet as large as Mercury.

The belt of asteroids forms a division between the four planets which are near the sun and the four more remote. The four interior planets, as the first group are termed, are all of moderate size, and of considerable density, averaging about five times that of water; and they all revolve on their axes in about twenty-four hours. The four exterior planets, on the other hand, are of greater bulk, but of comparatively little density, scarcely averaging that of water; and they revolve upon their axes with great rapidity, once in about ten hours. Neither Mercury nor Venus, so far as is known, is attended by satellites. The Earth has one, Mars two, Jupiter four, Saturn eight, and it is also surrounded by a series of luminous rings. Uranus has four moons, and Neptune one at the least. It is very probable, however, that both Uranus and Neptune are attended by satellites which have not yet been discovered, owing to their small size and the immense distance at which they are removed from us. Two of Jupiter's satellites and one of Saturn's are of greater dimensions than Mercury, and nearly as large as Mars. But the density of these moons is only about one-fifth that of their primaries, or about a twenty-fifth of the earth's density; while the density of Mars is nearly equal to that of the earth, and that of Mercury exceeds it.

Sir John Herschel gives the following illustration of the magnitude and distances of the different members of the solar system. If upon a level field a globe 2 feet in

diameter be placed to represent the sun, Mercury will be represented by a grain of mustard seed at a distance of 82 feet; Venus by a pea, at a distance of 142 feet; the Earth also by a pea, at a distance of 215 feet; Mars, a large pin's head, at a distance of 327 feet; the smaller planets by grains of sand, at distances varying from 500 to 600 feet; Jupiter, a moderate-sized orange, at the distance of a quarter of a mile; Saturn, a small orange, at the distance of nearly half a mile; Uranus, a full-sized cherry, at the distance of three-quarters of a mile; and Neptune, a good-sized plum, at a distance of about a mile and a quarter.

It has been mentioned that the exterior planets differ from the interior group in their periods of rotation. This period has not yet been ascertained in the case of Uranus and Neptune, but Saturn and Jupiter each revolves upon its axis in about ten hours. We should expect, therefore, that the polar compression would be much greater in their case than in that of the earth; and so we find it. While the polar compression on the earth is only $\frac{1}{297}$ of its diameter, that of Jupiter is $\frac{1}{17}$. In the case of Saturn, we find that the equatorial protuberance has broken away, owing to the centrifugal force, and now forms the belts or rings by which it is surrounded. It has also a very considerable polar compression. Recent investigations have proved that these rings are not solid, but consist of an infinite number of small bodies resembling meteorites, "small satellites of Saturn, out of which, at some future time, larger satellites will be compounded."

All the planets move round the sun in one direction, from west to east; and all turn upon their axes in the same direction, and so do the satellites, with one exception. This exception is found in the satellites of the planet Uranus, which move from east to west. Another remarkable fact about them is that the plane of their orbits is inclined to the ecliptic at an angle of 78° 38′, or is almost perpendicular to it. If, as we are led to conclude from analogy, the equator of Uranus lies nearly in the plane of the orbits of its moons, the axis of rotation must lie very nearly in the plane of its orbit. This must produce a curious effect upon its

seasons, as every part of its surface must in turn come under the vertical rays of the sun. And thus in the course of one revolution round the sun, which it accomplishes in 84 years, every portion of its surface is alternately exposed to the heat of the tropics and to the cold of the polar regions. In Jupiter, on the other hand, there can be little or no variety in the seasons, as the inclination of its axis is only 3°. In the case of Mars and of Saturn the inclination is rather more than that of the earth; in Venus it is considerably more; while in Mercury and Neptune the inclination has not yet been ascertained.

Vulcan.—It is a very general opinion now among astronomers that in addition to the planets already mentioned there is at least one smaller planet between Mercury and the sun. Leverrier, the great French mathematician, who shares with Mr Adams the honour of having discovered Neptune, found from a careful study of the orbit of Mercury that the greater axis was shifting more rapidly than he could account for (see p. 216), and he came to the conclusion that between the planet and the sun there must be matter in some form that had not yet been recognised. It might be a single planet or a group of planets, he could not decide, but some mass exerting the power of gravity must be there. Shortly after he had made this announcement he learned that M. Lescarbault, a doctor, had seen, on March 26, 1859, a round black spot on the sun's face, and had watched it travelling across like a planet in transit. Leverrier was at first disposed to doubt this statement, but after fully investigating the whole affair he came to the conclusion that an intra-Mercurial planet had been seen, and the name of *Vulcan* was given to it.

Year after year passed away, however, and though the reappearance of the planet was anxiously looked for, it could not be seen. During the total eclipse of the sun which was visible in America in July 1878, Professor Watson of Washington determined to make a careful search for the planet, and his trouble was rewarded. It appeared like a star of the fourth or fifth magnitude; and such is the character of Professor Watson as a careful and

accurate observer, that few now doubt that Vulcan has been rediscovered. It is, however, very small, being more like an asteroid than a planet. Its diameter has been estimated at 350 miles, its period about 24 days, and its distance from the sun about 15 million miles. A planet so small is quite unable to produce the perturbation detected by Leverrier, and it is not improbable that the rest of the disturbing force is due to a crowd of minute particles of matter which exist in the neighbourhood of the sun, and whose lustre forms what is called the *zodiacal light.*

Mercury is, with the exception of Vulcan, the smallest of the planets, its diameter being a little less than 3000 miles. Its mean distance from the sun is nearly 36 million miles, and the eccentricity of its orbit is very considerable, as at one time it is 14 million miles nearer to the sun than at another. It turns upon its axis in 24 hours 5 mins. Owing to its proximity to the sun, it can seldom be seen by the naked eye, and when it is visible it can only be seen immediately before sunset or a little after sunrise.

Venus is nearly as large as the earth, its polar diameter being 7550 miles. Its mean distance from the sun is nearly 67 million miles, and its orbit is inclined to the ecliptic at an angle of 3° 23′; while that of Mercury is inclined at an angle of 7°. The eccentricity of its orbit is very small. It turns upon its axis in 23 hours 21 minutes, and completes a revolution round the sun in 224 days. The inclination of its axis to its orbit is sometimes said to be as much as 50°, or even more, but there is great uncertainty upon the point. The inclination of the axis of Mercury has not been determined. Both Mercury and Venus, when viewed through a telescope, present phases like the moon; and in Venus a certain amount of twilight is occasionally seen upon the unilluminated part of the planet, thus proving that there must be an atmosphere.

Mars.—The polar diameter of Mars is about 4000 miles, and as its equatorial diameter is nearly 900 miles longer, there is considerable polar compression. Its mean distance

from the sun is 140 million miles; but as its eccentricity is nearly one-tenth of this, it is sometimes little more than 30 million miles distant from the earth. Mars rotates upon its axis in 24 hours 37 minutes, and its axis is inclined to its orbit nearly 29°. By means of a telescope we may detect on this planet certain brilliant white patches near the poles, which are probably masses of snow and ice, since they are seen to diminish with the approach of summer, and to increase during winter. Land and water have also been noticed with sufficient distinctness to be laid down on a map. The land has a reddish hue, owing to the reflection of the sun's rays and the absorption of the atmosphere; the water appears of a greenish tinge. The density of Mars is nearly equal to that of the earth, and it is attended by two satellites.

Jupiter, the largest of all the planets, has an equatorial diameter of 88,000 miles, but its polar diameter is 5000 miles shorter. Its density is only about equal to that of water, and rather less than that of the sun, so that it is probably still either in a liquid or gaseous state. It is supposed that its atmosphere is laden with clouds, and that the dark bands which cross its disc in the region of the equator are rifts in the cloudy masses. It turns upon its axis in about ten hours, and completes a revolution round the sun in about twelve years, its mean distance from the sun being 479 million miles. It is accompanied by four satellites, all rather larger than our moon. The nearest to Jupiter is about 267,000 miles from it; the most distant more than one million miles from it. These satellites were discovered by Galileo, and this was one of the first results of the invention of the telescope. Jupiter's moons, like our own, turn upon their axes in the same time in which they move round their primary planet. The eclipses of Jupiter's satellites are very frequent, and, as has been already explained, they afford an accurate means of determining longitude.

Velocity of Light.—After Jupiter's satellites were discovered and their eclipses observed, the times when the eclipses would occur were carefully calculated; but it was

found at first that the phenomena seldom happened at the right time. Sometimes the eclipses happened too soon, and sometimes too late. It occurred to Roemer, a Danish astronomer, that this discrepancy might be due to the fact that light was not instantaneous, but took a definite time to traverse space. He set to work to calculate this, and he found that when Jupiter and the earth were on the same side of the sun the eclipse occurred twenty-two minutes sooner than when the planet was on the opposite side of the sun. He concluded, therefore, that light took twenty-two minutes to traverse the length of the earth's orbit, and therefore eleven minutes to come from the sun. He was right in principle, but the result at which he arrived was, owing to the imperfections of the instruments then in use, not accurate. Delambre, a French mathematician, early in the present century, came to the conclusion, after careful investigation, that the time required for light to come to us from the sun is eight minutes thirteen seconds. This agrees very nearly with the result obtained by Dr Bradley from a consideration of the aberration of light.

Saturn, which ranks next to Jupiter in size, has an equatorial diameter of 72,000 miles, while the polar diameter is 7000 miles shorter. It is the least dense of all the planets, having only about one-eighth the earth's density, and only one-half of that of the sun. It is probably in a gaseous condition, and its disc is crossed by dark bands similar to those of Jupiter. It rotates upon its axis in ten hours and a half, and performs a revolution round the sun in about thirty years. Its axis is inclined to its orbit at an angle of nearly 27 degrees, thus differing from Jupiter, where the inclination is only about 3 degrees. Saturn is accompanied by eight satellites, the nearest of which is 120,000 miles from the planet, and the most remote about 2,000,000 miles distant. The most remarkable thing about Saturn is its series of rings, which are about 10,000 miles distant from the planet, and nearly in the same plane as its equator. The rings have a thickness of about 100 miles, but they extend in breadth about 37,570 miles; and as they reflect the light of the sun,

they must have a wonderful appearance when viewed from the surface of the planet. It is supposed now that they are neither solid nor liquid, but composed of myriads of small bodies, moving independently, each in its own orbit.

Uranus is about twice the distance of Saturn from the sun, and has about half that planet's diameter. It turns upon its axis in nine hours and a half, and performs a revolution round the sun in about eighty-four years. It has a greater density than Saturn, but less than Jupiter, and has probably a considerable temperature, as the spectroscope shows that to a certain extent it is self-luminous. Four moons have been detected, and it is remarkable that their motion is retrograde. This may be explained by supposing that the axis of the planet was tipped over about 100°, and that the true north pole is therefore really 12° below the plane of the ecliptic.

Neptune has a mean distance of 2746 million miles from the sun. It is rather larger than Uranus, and moves once round the sun in about 160 years. The time of its rotation is not known; its density is about the same as that of Uranus. One satellite has been observed, but, judging from analogy, we should expect that it has several others. The motion of this satellite is believed to be retrograde, and the explanation given above has been applied to this case. If it be the true one, Neptune must have tipped over about 150°.

Comets and Aerolites.—What is the precise part which comets play in the economy of the universe is not known. They are often of enormous size, but are composed—the tail portion, at least—of exceedingly thin vapour. Their brilliancy is mainly due to the reflected light of the sun, though, as we shall afterwards see, the spectroscope shows that the head or nucleus is self-luminous. They move in very elliptical orbits, at one time approaching very near the sun, and at another wandering far beyond the limits of Neptune. The periods in which they perform their revolutions round the sun vary greatly. One group revolve in orbits for the most part interior to that of Jupiter, and have periods from three

and a half to seven and a half years. To this class belongs *Encke's* comet, which has made twenty-six revolutions since its discovery in 1786. It has been noticed that its orbit is slowly diminishing, owing, as some think, to the resistance of the luminiferous ether which fills all space. Another of this group, known as *Biela's* comet, is remarkable from the fact that during its appearance in 1846 it was observed to divide in two, and the parts travelled side by side, maintaining a constant distance from each other. One of the best-known comets is that of *Halley*, which has a period of seventy-seven years. The astronomer foretold its appearance in 1759, and it arrived within a month of the computed time. It appeared again in 1835, within five days of the time calculated.

All these are called short-period comets. The long-period ones return at intervals of 2000, 3000, and even 100,000 years. *Donati's* comet, which presented such a brilliant appearance in 1858, has a period of 2100 years. The number of comets recorded from the earliest times, beginning with the Chinese annals, is about 800, but there are probably many thousands belonging to the solar system. Kepler spoke of them as resembling in number the fishes of the ocean.

Comets differ from planets not only in form, density, and in the great eccentricity of their orbits, but in other respects. All the planets, as we have already observed, revolve in orbits which pretty nearly coincide with the plane of the ecliptic, but comets perform their revolutions in every plane, sometimes almost at right angles to the ecliptic; and while some revolve round the sun in the same direction as the planets, others revolve in the opposite direction, that is, from east to west. In this respect they resemble those belts of aerolites which are met with in our system, and indeed some think they are identical with them.

Upon almost any clear night shooting-stars may be seen, but the months of August and November are especially remarkable for star-showers. And it has been noticed that the November meteors recur with increased brilliancy

at intervals of thirty-three years. It is supposed that there is a ring of material fragments revolving round the sun in a long ellipse, with a period of about thirty-three years; and that there is one part of the ring where the aerolites are much more densely packed than elsewhere. The orbit described by these fragments of matter crosses the earth's orbit near the position in which the earth is about the middle of November. Coming down somewhat aslant, the meteors rush into our atmosphere at the rate of more than forty miles per second. Ignited by friction in passing through the air, they become brilliantly luminous, and are known as shooting-stars. The heat is so intense that for the most part the aerolites are dissipated in vapour, but fragments of considerable size occasionally reach the earth, and what is called meteoric iron (p. 29) is supposed to have had this origin. The phenomena just described will take place to a greater or less extent every year, and hence the November meteors are regularly looked for; but at intervals of thirty-three years the earth will encounter the densest portion of the ring, and thus the display will be greater than usual.

The remarks just made apply especially to the November showers, but those which occur to a less extent in August, April, and other months have doubtless a similar origin. If the fragment which reaches the earth is chiefly stony in structure it is termed an *aerolite;* if mainly composed of iron, a *siderite;* while the term *siderolite* is applied to those which are half stony and half iron and nickel. The November meteors are called *Leonides*, because they all radiate from that part of the sky in which the constellation of Leo is placed; those of August diverge from the constellation of Perseus. Those centres from which the meteors radiate are called *radiant points;* and as nearly sixty of these have been determined, it is very probable that there are at least sixty rings of meteoric matter revolving round the sun similar to that which gives rise to the November showers.

The November group has an orbit of more than 1700 million miles in length, so that it extends as far as Uranus.

And if we may judge of the thickness of the ring by the time it takes the earth to pass through it, we shall conclude that it is not less than one million miles; and yet it is thought that there are other groups belonging to our system which may be still larger. It has been estimated that the total number of meteors, large and small, which the earth encounters in the course of the year amounts to 400,000,000. Of course the greater portion of these are turned into vapour, but occasionally fragments of considerable size reach the earth. An aerolite weighing six hundredweight, besides about a thousand smaller stones, fell in Hungary in June 1866.

Tempel's comet, which appeared in 1866, has a period and orbit identical with the ring of meteors which cause the November showers; another stream of meteors has been identified with Biela's comet; while a comet which was observed in 1862 has an orbit identical with the meteoric stream which causes an annual shower of shooting-stars in August. It has been suggested that all comets moved originally in paths that were either parabolas or hyperbolas, but that some of them have been drawn out of their course by the attraction of the larger planets, Jupiter, Saturn, and Uranus, and the parabola or hyperbola thus changed into an ellipse. When this happens the comet will return at regular intervals. The matter of which comets are composed is supposed to be identical with that which forms the numerous meteor swarms—a countless number of small fragments. As each of these fragments moves independently, it will happen that some will lag behind the others in moving round their orbit, and in time they will spread all over the path which the comet follows. The November meteors are supposed to have been produced by Tempel's comet, which was probably arrested by Uranus, and Leverrier thinks this took place about A.D. 126. The August meteors are much more ancient, as they are pretty evenly distributed throughout their orbit, while the November meteors have a denser portion in one part of the ring, which we encounter once in thirty-three years.

CHAPTER IX.

THE STARS: NEBULAR HYPOTHESIS.

In very early times, as we before remarked, astronomers distinguished between planets, or "wanderers," and fixed stars. Recent researches have proved that the stars are not really fixed, but that many of them, and probably all, have a certain motion in space, called their *proper* motion, to distinguish it from an apparent motion resulting from external causes. But though the old distinction between stars and planets no longer exists, other circumstances have been discovered respecting them which mark still more distinctly how stars differ from planets. Planets shine by the reflected light of the sun, just as the moon does, and as the earth would appear to do if viewed from the moon or from one of the planets; stars shine by their own light, like the sun itself; and each is probably the centre of a system of planets and satellites similar to the solar system. On a clear night about 3000 stars are visible to the naked eye. These, as we know, are not all of the same degree of brightness; and they have been divided into various classes or "magnitudes." Those visible to the naked eye are divided into six classes; but by the aid of telescopes we can discern many that would otherwise be invisible, and the classification has been carried to the sixteenth magnitude. It is said that by means of a powerful telescope at least 20,000,000 stars, down to the fourteenth magnitude, are visible.

Distance of the Stars.—We mentioned, in speaking of the means used to ascertain the size of the earth, that a base-line was first measured, and that then the angles made by viewing an object from either extremity

of the line were observed, and in this way the distance of the object could be ascertained. Precisely the same method was adopted in determining the distance of the moon; but in that case our base-line was the earth's radius. Now, knowing the distance of the sun, we have a very much larger base-line at our disposal for measuring the distance of the stars, for the distance in a straight line between the place in the orbit where the earth is in summer and where it is in winter is about 183,000,000 miles; and yet such is the distance of the stars, that when we view them from either extremity of this immense line the change in the position of those nearest to us is barely perceptible, and can only be detected by the most refined methods and the most accurate instruments. So far as we know, the star Alpha in the constellation of the *Centaur* is the nearest of all the fixed stars; and yet its parallax is only 0·9187″, or less than one second. This star, though the nearest to us, is yet 200,000 times farther distant than the sun; and light, which comes to us from that luminary in eight minutes, would require three years and a half to come from *α Centauri*. It will be recollected that, when speaking of the size and distances of the planets, we mentioned the illustration used by Sir John Herschel, to the effect that if the sun were represented by a globe two feet in diameter, we might represent the earth by a small pea at a distance of 215 feet, and Neptune by a good-sized plum at a distance of a mile and a quarter. Now, making use of the same scale, the nearest fixed star would be represented by a globe 9000 miles distant.

It has been calculated that if the sun were removed from us to the distance of *α Centauri* it would only shine with one-third its light; consequently, if we suppose this star to be of equal brilliancy with the sun, it must present to us a surface three times as large as the sun's, and must therefore be at least five times its size. As a matter of fact, the star is double; but as one of the pair only yields one-seventh of the total light, it is fair to suppose that the other greatly exceeds the sun in bulk. The parallax of

twenty other stars has been calculated; but of course the results are not so reliable as those of *α Centauri*, since the amount of parallax is exceedingly small. *Sirius*, the Dog-star, and by far the most brilliant in the northern hemisphere, is one of these, and its distance is said to be 1,375,000 times farther than that of the sun; while the *Pole-star*, another one, is twice the distance of Sirius. It has been calculated that if the sun were removed to the distance of Sirius it would shine with only $\frac{1}{150}$ part of its lustre, and it has been conjectured, therefore, that the diameter of Sirius must be at least twelve times greater than that of the sun. Of this, however, we cannot be certain, for spectrum analysis has taught us, among other things, that stars shine with different degrees of brightness, owing probably to differences of temperature, and that Sirius is among the hottest and brightest of all. That the brightness of any particular star is no certain indication of its distance may be seen in the case of the star named 61 *Cygni*, another of those whose parallax has been calculated. This star is of the sixth magnitude, and yet it is only about one-fourth the distance of Sirius. Still there is little doubt that, speaking generally, stars of the second and third magnitude are more distant than those of the first, and that those of the sixteenth magnitude are the most distant of all with which we are acquainted. Judging in this manner, it has been estimated that light, which travels at the rate of 186,000 miles in a second, would take 3500 years to come from a star of the twelfth magnitude.

Double Stars.—A large number of stars which to the naked eye appear single are found, when viewed through the telescope, to consist of two or more stars. In very many cases the two component stars are unequally bright, and may be at immense distances from one another, being simply situated nearly in the same line as viewed from the earth; such stars are said to be *optically double*. In other cases, however, there is a physical connexion between the two, and they are found to revolve round a common centre of gravity. These are true *binary* stars

or systems. More than 6000 double stars are known, and of these about 700 have been proved to be true binary systems. One of these is *α Centauri*, the two members of the system being about as far from each other as Uranus is from the sun, and they complete a revolution round their common centre in seventy-five years. The star known as 61 *Cygni* is also double, the two stars being 4,275,000,000 miles apart. One of the most interesting examples of these binary systems is afforded by the star *ε Lyræ*. To the naked eye it looks like a faint single star; a small telescope is sufficient to show that it is double, and a powerful instrument reveals the fact that each star composing this double is itself double. Here, then, we have four suns in two pairs, each pair revolving round a common centre, while the two pairs, considered as units, revolve round another centre of gravity. One pair makes a revolution in about 1000 years; the other pair, which are wider apart, take about twice that time, and it has been calculated that the double systems may make a revolution round their common centre in about one million years.* An interesting circumstance connected with binary stars is that very often the two stars are of different and brightly contrasted colours: thus one star is orange and the other blue; one red and the other green; or one purple and the other white.

In connexion with this subject it is interesting to notice that our sun itself has a proper motion, and is moving in the direction of a star in the constellation of *Hercules*, at the rate of 154,000,000 miles in a year. Of course, all analogy leads us to believe that the path in which the sun is moving is a portion of some immense orbit, and it has been conjectured that the centre of this orbit is the star *Alcyone*, one of the Pleiades. Since the attention of astronomers was first directed to the proper motion of stars it has been found that the instances in which this motion can be detected are very numerous: there are at least 1500 stars in which this motion is undoubted. It thus appears that the sidereal system is much more com-

* Lockyer: *Lessons in Astronomy.*

plicated than is generally supposed, and it is not improbable that all the stars which compose our firmament may be connected together by the law of gravitation. This proper motion of the stars may also help to explain the fact that some stars decrease or increase in brilliancy in the course of ages. Two centuries ago the star δ of the Great Bear was as bright as the others, but it has now sunk to the fourth magnitude. The star ϵ in the constellation of the Ship, which thirty years ago was next to Sirius in brilliancy, is now barely discernible in the darkest and clearest night.* Is it not possible that these stars may now be much farther from us than formerly?

Variable Stars.—The true variable stars, however, undergo much more rapid changes than those to which we have referred, and their variation is capable of a different explanation. One of the most remarkable of these is *Mira* (o Ceti). It has a period of 331 days; that is to say, it goes through its cycle of variation in that time. It sometimes shines as a star of the second magnitude, and then goes on decreasing in brilliancy until it becomes invisible, in which state it continues for about five months. It is said that between the years 1672 and 1676 it was not visible at all. *Algol* (β Persei) is another remarkable star. It usually appears as a star of the second magnitude, and remains so for two days and a half. It then suddenly diminishes in brightness, and in about three hours and a half dwindles to a star of the fourth magnitude. After remaining thus a quarter of an hour it begins to increase in brilliancy, and in three hours and a half returns to its former state. Its period is thus less than three days. The star β Lyræ, situated a little south of Vega, has a double period—that is, two maxima and two minima periods of brightness—in the course of thirteen years; the difference between the maximum and minimum brilliancy is only, however, one degree. But while the two maxima are equal, the two minima are unequal. The star δ Cephei has a period of $5\frac{1}{8}$ days, and in that time changes from a star of the third to that of the fifth maguitude.

* Proctor.

These periodic changes in the lustre of certain stars may be due either to the revolution of some dark bodies round them, just as the planets move round the sun; or to the rotation of the stars upon their axes, one side being brighter than the other. A third supposition is that the stars may be subject to periodic changes similar to those which produce sun-spots. Professor Balfour Stewart thinks the sun itself is a variable star with a period of about eleven years.

Nebulæ.—The word *nebula* means a little cloud, and the term was first applied to those hazy spots of light which are visible on a clear night in the constellations of Orion, Perseus, Andromeda, and others. A small telescope will show that some of these are resolvable into stars, but reveals, at the same time, other nebulæ more distant. Larger telescopes have resolved many of these, but others still remain nebulous. As, however, every increase of telescopic power has been accompanied by the discovery that some one or other of the nebulæ that had before resisted all attempts to resolve it has been found to consist of thousands of stars, the opinion became pretty general, a few years ago, that all the nebulæ were in reality star-clusters, and that some remained unresolved solely on account of the immense distance they were from us. The spectroscope, however, has taught us that some of the nebulæ are merely cloud-like masses, and not star-clusters. On August 29, 1864, Mr Huggins directed his telescope, armed with the spectrum apparatus, to the nebula in the constellation of *Draco*, and he found that the spectrum was totally different from that produced by the light of the sun or of the stars; in short, he proved conclusively that the source of light in this particular instance was a glowing gas. It appears, then, that under the term nebulæ we include two distinct things: a star-cluster and a body of incandescent gas. To avoid confusion, therefore, it would be well to term those nebulæ that have been resolved *star-clusters*, leaving the old term to those that are proved to be mere masses of cloudy matter, as well as to those that have not yet been resolved.

It has long been the opinion of astronomers that we ourselves live in a star-cluster similar to those that have been revealed by the telescope. According to this opinion, the 20,000,000 stars revealed to us by the telescope form but one cluster out of thousands, perhaps millions, scattered through infinite space. The star-cluster, or "firmament," as it is sometimes called, to which we belong is supposed to resemble in shape a cheese or a grindstone, and the sun is situated not far from the centre of it. If we look towards the edge of this cluster the stars will appear to be crowded together, and hence the appearance of the galaxy or Milky Way, "powdered with stars." Looking towards the sides of the firmament—at right angles to the Milky Way—the stars are fewer in number, and hence look less crowded. A simple illustration may explain this. If we are walking in a small wood or plantation about half a mile in length and about 100 yards wide, where the trees are planted at almost equal distances from each other, it will be seen at once that, if we look in the direction of the length of the plantation, the trees will appear so thickly planted that we cannot see through them; but if we take a side view, though the trees are equally close, we shall observe open spaces between, and may probably discern objects in the country beyond. Now, so it is with the heavens. The stars are not really more numerous in the direction of the Milky Way, but they appear to be, since that is the direction in which our "firmament" has the greatest extension. The star-clusters outside our own are most numerous in a zone which crosses the Milky Way at right angles, those parts of the heavens farthest away from the galaxy being richest in them. These star-clusters vary in form. One in the constellation of the Bull (Taurus) has been named from its shape the *Crab-cluster;* another in Cancer has been termed the *Præsepe*, or Bee-hive. Perhaps the finest is that of ω Centauri.

Mr R. A. Proctor, however, who has devoted considerable attention to this subject, is of opinion that all the nebulæ and star-clusters exist within the limits of the sidereal system; in other words, that instead of a number of

firmaments scattered throughout space, at wide intervals apart, there is only one. "I reason thus," he tells us, "because I have been led to the conclusion that our sidereal system is much more extensive than has been hitherto supposed. It is not that I draw the nebulæ inwards to the star depths, but that I extend the star depths outwards so as to include the nebulæ." * Of course, if this opinion be correct, there must be a real and not a merely apparent aggregation of stars in the Milky Way.

The **Nebular Hypothesis.**—The existence of real nebulæ, or cloud-like masses of incandescent gas, adds considerable weight to the theory propounded by Kant and Laplace to account for the origin of the planetary bodies. Kant was led to his theory from considering the striking fact that the planets all revolve round the sun in nearly the same plane, and all in the same direction, from east to west. These facts seemed to him to point to a common origin. He supposed, therefore, that at one time the sun extended, in a less dense condition and in the form of a disc, as far as the limits of our system, and revolved rapidly on its axis. Certain portions of the outer rim of the disc, being more dense than others, would attract the rarer portions of matter round them, and thus planets would successively be formed.

Laplace, with a profounder knowledge of mathematics than the German philosopher, improved upon his theory. He, like Kant, believed that originally the sun extended beyond the limits of the solar system and revolved rapidly on its axis. This revolution would give a certain centrifugal force to the outer rim; and as the process of condensation went on the rapidity of the revolution would be increased, and consequently there would be an increase in the centrifugal force. A time would at length arrive when the centrifugal force of the outer rim would balance the power of attraction towards the centre. The rim of gaseous matter would then no longer take part in the process of condensation, but would break off in a ring which would preserve its original rate of rotation. Other rings of less diameter would subsequently be formed, until at length

the sun assumed a globular shape. Now, if any of these rings were of nearly uniform density, it would remain a ring composed of a vast number of smaller particles, something similar to the belt of asteroids which occurs between Mars and Jupiter. If, however, any portion of the ring were more dense than the rest, it would attract the other less dense matter round it and form a planet. The larger rings would of course form larger planets, but they would be less dense than those formed subsequently. Satellites would be formed from the planets, just as their primaries had been thrown off by the sun. In Saturn we have the solar system in miniature. There are eight moons, corresponding to the eight planets, and we also have an example of a ring which is of such uniform density that it has not been broken up so as to form a moon. If among the materials of the solar atmosphere there were any so rare and volatile that they would not unite themselves either with a ring or a planet, they would continue to revolve round the sun, presenting an appearance like that of zodiacal light.*

Now, in favour of this hypothesis we have the fact that in several parts of the universe there are, as we have already said, real nebulæ or masses of gaseous matter such as we suppose the sun to have originally been. Several of the nebulæ, also, are of such a form as to indicate that a process of rotation and condensation is taking place. Some, like the fine example to be seen in *Canes Venatici*, are spiral in shape, others consist of a huge globular mass surrounded apparently by rings. They present the exact appearance that Saturn does when its ring is seen through a telescope edgewise, and hence they have been called *Saturnine* nebulæ. The process of condensation, which changes the nebulous matter into a sun, would be accompanied by an increase of temperature. Indeed, it is a curious fact, well known to physicists, that the more heat a gaseous body radiates the hotter it becomes. A time will arrive, however, when continued condensation will reduce the planet or star, as the case may be, to a fluid

* Newcomb: *Popular Astronomy.*

state, and then the process of cooling sets in. Now, as we shall afterwards find, astronomers divide stars into four classes according to their temperature, and the sun is placed in the second class. Some stars, like Sirius and Vega, are hotter than the sun, others are probably much cooler. It is thus possible that in the different classes of stars we may see stages in the sun's history. With the present magnitude of the sun his whole diameter need but contract about four miles in a century to produce all the heat which he radiates; and it has been calculated that he will continue to give out light and heat for ten million years at least. Looking backward, we can see that in former times —perhaps during geological ages—he must have been much brighter and hotter, as well as larger, though less dense, than he now is.*

Of course, if the nebular hypothesis be correct, the planets, including the earth, must at one time have possessed a temperature as high as that of the sun; being however, much smaller bodies, they would cool more rapidly. It is not improbable that the exterior planets, owing to their greater size, have at present a much higher temperature than the earth; they have not cooled so rapidly, hence probably they are still in a gaseous condition. The moon, according to the hypothesis, must be of more recent origin than the earth, yet it seems to have parted with all its native heat.

* Newcomb.

CHAPTER X.

Spectrum Analysis.

It was explained on a previous page that the white light of the sun is made up of seven primary colours, which possess different degrees of refrangibility, red being the least refrangible, violet the most. Solar light, we know, is caused by a vibration in the molecules which compose the sun, and this vibration, communicated to the luminiferous ether, produces a series of waves which strike upon the retina and produce the sensation of vision. The waves thus produced are not all of equal length, and hence travel with different velocities, since they all reach the eye at the same time. The violet waves are the smallest and quickest; the red waves the largest. Beyond the red rays, however, there are others of still larger wave-length which are invisible, but are powerful to produce heat; while beyond the violet are rays of smaller wave-length which produce that peculiar chemical action called *actinism*, upon which the art of the photographer depends, and which is so important to vegetation. It would seem that the human eye is adapted to receive a limited number of vibrations per second; waves of a greater or less velocity produce no sensation upon the retina. Heat, then, is of the same nature as light; it only differs from it in being produced by larger waves. This also is the only distinction between one colour and another in the solar spectrum; they differ only in wave-length.

An illustration which we have used before may, perhaps, make still clearer the connexion between light, heat, and colour. If we thrust a poker into the fire, we know that the iron becomes hot before it changes colour. After a time it turns a dull red, then changes to a bright yellow,

and if allowed to remain long enough in the fire will reach what is called a white heat. Now, if the rays produced by the poker were passed through a prism, there would be no spectrum until the iron had reached a certain temperature. Then the red end of the spectrum would appear; afterwards, as the heat increased, the orange and yellow parts would be seen; and at length, when the iron had reached a white heat, the whole spectrum, from red to violet, would be visible. The explanation is, that so soon as the iron was thrust into the fire its molecules began to vibrate, or rather their vibrations increased in number and intensity, and the waves produced in the surrounding ether became more numerous. For a time they were too large to make any impression upon the eye, but smaller and smaller waves are produced by more rapid vibrations, until at length they become visible, and gradually all the colours of the spectrum appear.

The spectrum produced by iron when raised to a high temperature is, as we have said, a rainbow-coloured band. If the source of light, however, instead of being a solid, be a glowing gas or vapour, the spectrum is a dark ground crossed with bright lines of various colours, according to the part of the spectrum where they appear. Each vapour, between given limits of temperature and pressure, has its characteristic set of bright lines. Thus the vapour of potassium produces two red lines and a violet one; sodium, a strong yellow one; calcium, a faint red line, a bright orange one, several of yellow and green, and one of indigo. When the solar spectrum (see coloured chart) is carefully examined, it is found to differ both from the spectra produced by incandescent solids and from those of glowing vapours; it is a rainbow-coloured band, crossed by a large number of dark lines.

Solar Spectrum.—These dark lines were first noticed by Wollaston in 1802, who, however, made no attempt to explain them. Fraunhofer, who rediscovered them in 1814, examined them with great attention and care, and counted, mapped, and lettered 576 of them; hence they have ever since been called "Fraunhofer's lines." On

comparing the solar spectrum, thus carefully mapped out, with the spectra of various gases, it was noticed that certain of the dark lines coincided in position with some of the bright lines produced by glowing vapours. Thus Fraunhofer himself pointed out that the bright orange line of the vapour of sodium agreed in position with the dark line D of the solar spectrum. At this point the investigation was taken up by another German physicist named Kirchhoff, and after a series of experiments he came to the conclusion that the dark lines in the solar spectrum were due to absorption, and he announced as a result the following law :—"Every substance which emits at a given temperature rays of a certain order of refrangibility, possesses the power, at the same temperature, of absorbing rays of the same order of refrangibility." In other words, if any substance be raised by heat to an incandescent vapour, and thus gives out a particular kind of light, it has power to absorb the same coloured light.

In the solar spectrum there are some thousands of dark lines; they are so numerous that when seen through the spectroscope they seem nearly to fill up the whole space occupied by the spectrum, and yet are so thin that they do not appreciably detract from the total amount of light that comes to us.* These lines, it seems, then, are caused by absorption. The light which comes from the sun passes through certain glowing vapours, and each vapour absorbs a certain portion. These vapours must either be in the sun's atmosphere or in our own. They can scarcely be in our own, for it is difficult to understand how the atmosphere could contain such a number of metallic vapours as the dark lines of the solar spectrum indicate. Besides, if this were so, the spectrum of each star would be the same as that of the sun, which is not the case. We are driven to the conclusion, therefore, that the vapours exist in the sun's atmosphere.

The next step was to discover what were the vapours which exist in the solar atmosphere. The dark line D, we have already mentioned, coincides with the bright line of

* Roscoe.

sodium, and so it is concluded that the metal sodium exists in an incandescent state in the sun's atmosphere. Continuing his researches, Kirchhoff found that iron, calcium, magnesium, and chromium were also present; and later researches have added to these hydrogen, barium, aluminium, manganese, cobalt, nickel, zinc, copper, titanium, and cadmium. It is also said that oxygen has been detected. It is very probable, indeed, that all the elementary substances found in the earth's crust are present in the sun, but many of them may be in such a condition as not to be detected by the spectroscope.

So far we seem to have established these three principles, which it will be well to keep in mind:—

1. An incandescent solid or liquid gives a continuous spectrum.

2. A glowing vapour gives a spectrum of bright lines or bands on a black ground, each vapour having, between given limits of temperature and pressure, its characteristic set of bright lines or bands.

3. An incandescent solid or liquid body shining through absorbent vapours gives a continuous spectrum crossed by dark lines or bands, these lines or bands having the same position as the bright lines or bands belonging to the spectra of those vapours at the same temperature and pressure.

We may add that some vapours (and probably all) at a very high pressure give continuous spectra, like solids and liquids. Judging, then, from the character of the solar spectrum, we should conclude that the sun consists of a solid or liquid nucleus in a state of intense heat, emitting, therefore, rays of all orders of refrangibility; and the rays thus emitted are partially absorbed by the vapours in the sun's atmosphere. This opinion, first put forth by Kirchhoff, is very generally admitted; but it is by no means certain that the sun is either a solid or liquid body. Its density is only one-fourth that of the earth, or little more than that of water; and it is quite possible, as we have seen, that it may be a densely gaseous body, though the preponderance of opinion is in favour of a solid or liquid nucleus.

When it had been clearly established that the dark lines in the solar spectrum were due to incandescent metallic vapours in the solar atmosphere, it occurred to Professor Young of America that it might be possible, during a total eclipse of the sun, to obtain a spectrum of these vapours apart from the solar spectrum; and it will be evident that if these spectra could, as it were, be isolated they ought to present a series of bright lines on a black ground. In the eclipses of 1868 and 1869 these bright lines could not be detected, and hence it was clear that the complex solar atmosphere to which Fraunhofer's lines are due did not extend very far from the photosphere, or bright surface of the sun; and that if these bright lines were visible at all, it could only be for a second or two after totality begins, or just before it ends. In the solar eclipse of 1870 Professor Young directed his spectroscope towards the part of the sun's edge which was the last to disappear: "So long as any portion of the sun was visible he saw the usual solar spectrum, growing fainter and fainter, however, as the sun gradually disappeared from view. At length this spectrum disappeared altogether, and then there suddenly appeared the most beautiful spectacle spectroscopic observations can afford—thousands of bright lines, the spectrum of that complex solar atmosphere which, under ordinary conditions, produces by its absorptive action the corresponding dark lines of the solar spectrum. The spectacle lasted but a few seconds; for the advancing body of the moon quickly concealed the solar atmosphere, as it had already concealed the solar globe; but just before the solar globe reappeared the atmosphere was again in view, without direct sunlight, for a few seconds; and during that time the beautiful spectrum of multitudinous bright lines of all the colours of the rainbow (ranged, too, in rainbow sequence) was again seen."*

That particular part of the sun's atmosphere which contains the incandescent metallic vapour is, it appears, then, a comparatively narrow band extending not very far above the photosphere. It has been called the *reversing layer*,

* Proctor: *Spectroscope*, p. 79.

because it is here that portions of the sun's light are reversed, and the Fraunhofer lines produced. Rising high above this portion of the solar atmosphere is the *chromosphere*, which is composed in a great measure of glowing hydrogen. Beyond this again is the *corona*, which extends in some instances a distance of two or three times the sun's diameter above the photosphere.

The spectroscope consists generally of three telescopes mounted upon a common stand, and whose axes converge towards a prism of flint glass. The use of the three telescopes will be best learned from the diagram (Fig. 25). Let F be a flame, the light of which is to be examined. The rays from F fall upon a lens in the tube A, and converge to a point, *b*, within the tube which is the principal focus of a second lens at *c*; hence they issue from the tube in parallel rays, and fall upon the prism P. On leaving the prism the light is decomposed, and enters the observing telescope B, where an inverted image of the spectrum is formed at *e*, and this is magnified by the ocular. The telescope C is used for the purpose of measuring the relative distances of the lines of the spectrum. It contains a micrometer, *m*, carefully marked on a transparent plate, and when the scale is lit up by a lamp, G, placed behind it, a magnified image of the micrometer is thrown upon the face of the prism, and this is reflected into the observing tube along with the beam of light to be analyzed. The micrometer is connected with screws, by means of which it can be moved in the direction of the spectrum laterally, and raised or lowered as may be required.

We have spoken of one prism only; generally, however, several prisms are used in a spectroscope, in order to increase the dispersion of the spectrum, for by this means the dark lines are more clearly shown. In the large spectroscope used at Kew a "battery" of prisms are arranged in a semicircle, and the rays of light, after passing through all of them, enter the observing telescope. One of the simplest forms of the spectroscope is one sold by Messrs Browning. It consists of seven prisms of different kinds of glass, arranged in a straight line, dove-

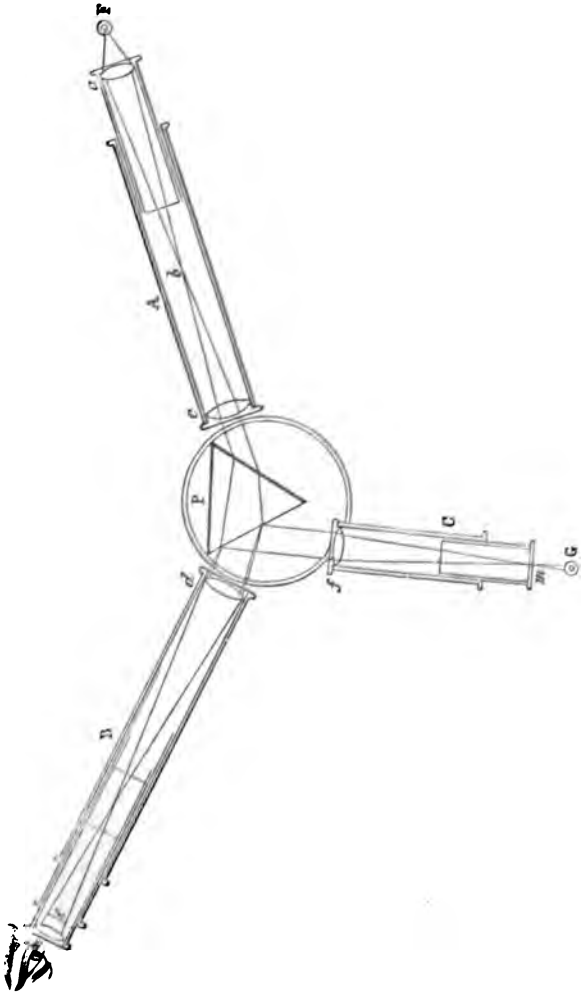


FIG. 23.

tailing into each other, and enclosed in a tube three and a half inches long, which may be put into the waistcoat pocket.

Kirchhoff, having discovered the meaning of the dark lines in the solar spectrum, followed up the subject by next turning his attention to the spectra of the stars. Here he found the same rainbow-coloured band crossed with dark lines, but the lines did not coincide with those of the solar spectrum. We learn from this that the stars are self-luminous, and that, like the sun, each consists of a hot central nucleus surrounded by an atmosphere containing vapours which absorb a certain portion of the light; and by studying the dark lines of the various spectra it has been found possible to determine what metallic vapours are present in those distant orbs. Among the metals that have thus been detected we may mention hydrogen, magnesium, sodium, and iron. We have already mentioned that Mr Huggins, by the important discovery which he made in 1864, proved that the true nebulæ are of the nature of glowing gas. The spectrum was a black ground crossed by three bright lines of a greenish-blue colour. One of these lines has been identified with the F line in hydrogen, and another with one of the nitrogen lines. The spectra of the planets is the same as that of the sun, only fainter, showing that they shine by reflected light.

Spectrum analysis has been applied with good results in explaining the nature of "new" and variable stars. In May 1866 a very small star, known as T *Corona borealis*, suddenly blazed forth, and attained the second degree of magnitude; it then slowly faded, with alternations of brightness, during several months, and is now reduced to the tenth magnitude. The spectrum of this star, when at its brightest, was observed by Mr Huggins, and found to present the ordinary stellar spectrum crossed by four *bright lines*, two of which were identified with those of hydrogen. Now, it has been determined by careful experiment that when the glowing vapours which surround an incandescent body absorb light they are cooler than the central body. Thus the metallic vapours which exist in

the reversing layer, though intensely hot, are yet cooler than the photosphere of the sun. If the surrounding vapours are of a higher temperature than the nucleus, they cause bright lines to appear in the spectrum. If they are of the same temperature they will just emit sufficient light to compensate for that which they absorb, in which case there will remain no trace of their presence. It will appear from this that when T *Corona borealis* was examined by Mr Huggins, the incandescent hydrogen present in the stellar atmosphere was actually of a higher temperature than the central nucleus itself. This speaks of some tremendous disturbance in the atmosphere of that distant star. At present the bright lines are absent from the spectrum, and the star is now invisible to the naked eye.

Ten years later, in November 1876, a new star was discovered by Dr Julius Schmidt, of the Athens Observatory, in the constellation of the Swan (*Cygnus*). When first observed, the star *Nova*, as it was named, was of the third magnitude, and of a strong yellow colour. When observed by M. Cornu, of the Paris Observatory, early in December, it had changed to a green colour, and was of the fifth magnitude. A faint continuous spectrum, but almost interrupted between the green and blue, was observed, crossed by bright lines, some of which corresponded to those of hydrogen. Since then the brilliancy of the star has rapidly diminished, and is now no longer visible to the naked eye. This decrease in brilliancy was accompanied by a change in the spectrum, and Lord Lindsay, writing to the *Times* in September of the following year, announced that the continuous spectrum had entirely disappeared, and that it then presented the spectrum of a nebula, consisting of a black ground crossed by one bright line. Mr Lockyer is of opinion that *Nova* was not a star at all, but a comparatively small mass of meteoric matter at no great distance from us. He is led to this opinion partly from the spectrum which it presented, and partly from the rapid decrease in brilliancy. "If," says he, "any star, properly so called, were to become 'a world on fire,' were 'to burst into flames,' or, in less poetical lan-

guage, were to be driven either into a condition of incandescence absolutely, or to have its incandescence increased, there can be little doubt that thousands or millions of years would be necessary for the reduction of its light to the original intensity."—*Nature*, No. 411.

But not only can we, by means of the spectroscope, determine the physical constitution of bodies at an inconceivable distance from us; we can also say whether these bodies are stationary, approaching towards, or receding from us. Before attempting to explain this, let us use a simple illustration. Suppose we are standing at some station expecting news of some event in progress at a distance, say six miles, from us, and that the news is brought every half hour by messengers who walk at the rate of four miles an hour. After a time we will suppose that the messengers are taken up by an omnibus, which begins to move slowly towards us at the rate of two miles an hour. If now the messengers are despatched from the omnibus at intervals of half an hour, as before, it will be evident that they will begin to reach our station more quickly. For, suppose a messenger starts with the omnibus, of course, as he is going at twice the speed, he soon leaves it behind. At the end of half an hour the omnibus has proceeded one mile; the second messenger, therefore, has a mile less to journey than his predecessor, consequently he saves a quarter of an hour, and comes into our station only a quarter of an hour behind the first messenger, instead of half an hour. The third messenger has a mile less to travel than the second, and so gains a quarter of an hour upon him; and so with the fourth and following. Thus, owing to the movement of the omnibus towards us, the messengers, instead of arriving every half hour, begin to arrive every quarter of an hour. If, however, the omnibus, instead of coming towards us, should go from us, the interval between the messengers would be increased.

Now, apply this to a distant source of light, such as the sun or a star. This body, by the vibration of its molecules, causes a series of waves in the luminiferous ether, and if

the body be stationary these waves succeed each other regularly, producing the various colours of the spectrum. If the star, however, be coming towards us, the waves will succeed each other more rapidly, and we might conceive of the velocity of the star coming towards us to be so great as to change the red waves into orange, the orange into yellow, and so to cause the whole spectrum to move from left to right, or from the red towards the violet. On the other hand, if the star were receding from us with equal velocity, there would be a movement of the spectrum in the opposite direction. Such, however, is the velocity of light when compared with the motion of the stars, that in no case is this movement sufficient to change one part of the spectrum into another colour; still a change may be detected, and even measured. The spectra of the stars, like that of the sun, are crossed with a number of dark lines, some of which are very close together. Now, by means of the micrometer it is possible to detect the slightest movement either in one direction or the other, and thus not only can the movement of a star be determined, but also the direction of the motion and the rate per second.

Mr Huggins has shown that Sirius, Betelgeux, Castor, and other stars, including five belonging to the Great Bear, are receding from the sun at rates varying from seventeen to thirty miles per second; while Arcturus, Vega, α Cygni, and α Ursæ Majoris, are approaching the sun still more rapidly.

So familiar, indeed, are spectroscopists with this mode of measuring the motions of a source of light, that the rate at which those glowing masses of hydrogen, which have given a name to the chromosphere, dart up from the surface of the sun can be accurately ascertained. They can measure the heights to which they rise, the rate at which they ascend or descend, and can determine the very form which those cloud-like masses assume.

CHAPTER XI.

Physical Constitution of the Universe.

Having thus briefly noticed some of the results obtained by spectrum analysis, let us consider their bearing upon the nebular hypothesis. Now, the first thing that will probably strike any one who considers the theory attentively will be this: if the nebular hypothesis be correct, the nebula ought to contain potentially all the elements which we find upon the earth. If the earth has been developed from a nebula, it is quite possible, nay, highly probable, that the various constituents which form the solid part of our globe have undergone many changes; they were all at one time, for example, in a gaseous condition. Still, the elements of matter—if they are really elements—must have been present in the nebula as they are present in the earth. What does spectrum analysis say on this point? At first sight it seems to negative the hypothesis. We have already stated that the only element which Mr Huggins can trace with any certainty in the nebulæ proper is hydrogen. But the question arises, Are the so-called chemical elements really simple bodies, or are they compounds? This question, as we hinted in a previous chapter, has been raised by Mr Norman Lockyer, without any reference to the question of the nebular hypothesis, but it will be seen that it has a distinct bearing upon the question, and we propose very briefly to give a brief outline of his line of argument.

Elements of Matter.—One result of the study of the stars by means of spectrum analysis is, that these bodies have been divided into four classes according to their temperature. First of all we have those which shine with a white or bluish-white colour, such as Sirius, Vega, Regulus, and some of

those in the constellation of the Great Bear. Next we have the yellow stars, such as Aldebaran, Arcturus, Capella, and Procyon, and to this class the sun belongs. The third class includes Betelgeux and others, mostly of a red or orange colour. Lastly, there are certain small red stars where the temperature is comparatively low. Now, what is very remarkable is, that the hotter any particular star is, the simpler is its spectrum. In stars of the first class the dark lines are comparatively few, and those present indicate hydrogen, calcium, and magnesium chiefly. In the second class the spectra closely resemble that of the sun; there are a large number of fine lines, and, in addition to the metals already mentioned, we find traces of iron, barium, and other substances. The spectrum of a star belonging to the third class resembles that of a sun-spot. The dark lines are very numerous, and in some parts of the spectrum crowded together; but the hydrogen and calcium lines are scarcely distinguishable. The spectrum of the fourth class is characterized by three bright bands separated by intervening dark spaces. The brightest band lies in the green, the others in the blue and red. The bands are brightest on the side toward the violet, where the light terminates sharply, while towards the red they fade gradually into darkness, thus giving what is termed a "fluted" appearance to the spectrum. Such a spectrum indicates the presence of compounds of metallic with non-metallic elements, and also of non-metallic elements alone.

Now, if we suppose that the "elementary" bodies are really compound, and that they may be resolved into their constituents by the application of a very high temperature, we can understand the different appearances presented by the spectra belonging to the different orders of stars. We may suppose that the compounds we find present in the coolest stars are dissociated by increased temperature in those of the third class, and reduced to what we term elements; and that a still higher temperature carries on the analysis further, and that several of the elementary bodies disappear, being decomposed into something still more elementary. Thus the few metals which can be traced in

the hottest stars, and which we at present term hydrogen, calcium, and magnesium respectively, may in reality be elements out of which the elementary substances known to chemists are compounded. This was a conclusion at which Mr Lockyer had arrived several years ago, and he has been confirmed in his opinion by the result of his laborious researches into the constitution of the sun.

For the last five years Mr Lockyer has been engaged upon the preparation of a map of the solar spectrum on a large scale, the work including a comparison of the Fraunhofer lines with those visible in the spectrum of the vapour of each of the metallic elements in the electric arc. To give an idea of the thoroughness of the work, we are told that "the complete spectrum of the sun, on the scale of the working map, will be half a furlong long; that to map the metallic lines and purify the spectra more than 100,000 observations have been made, and about 2000 photographs taken. In some of these photographs we have vapours compared with the sun; in others, vapours compared with each other; and others again have been taken to show which lines are long and which are short in the spectra."

In making these various observations it was of the utmost importance that the metals used should be as pure as possible. But as it is almost impossible to obtain perfectly pure substances, the photographs have been carefully compared in order to eliminate the lines due to impurities. It may be necessary here to explain that all the lines in a given spectrum are not of the same length nor of the same thickness. Now, the theory upon which Mr Lockyer worked in the process of purification was this: if a metal contain an alloy, the lines due to that alloy would be added to the spectrum of the metal. If the alloy were present in a very small quantity, only the longest and brightest line belonging to it might be visible; if in greater quantity, the finer lines would also appear. Hence the absence of a particular element as an impurity was taken for granted if its longest and strongest line were absent. Now, as each element has its own characteristic lines, there ought to be no coincidences between the photographs of different spectra. If

such coincidences occur, it has been usual to attribute them to impurities. But this hypothesis, Mr Lockyer tells us, will not hold good. The result of four years' careful labour has been to prove that short-line coincidences occur in the spectra of many metals "the impurities of which have been eliminated, or in which the freedom from impurity has been demonstrated by the absence of the longest lines."

In seeking to explain these short-line coincidences, Mr Lockyer was led to consider the hypothesis he had formed four or five years previously, and to which we have already referred. It seemed to him that these lines might indicate the existence of some substances common to the so-called elements; in other words, that the elements themselves might be compounds, having certain constituents in common. In order to test this hypothesis, it is necessary to consider what are the spectroscopic phenomena presented by a compound when exposed to a gradual increase of temperature. In the case of an alloy, as we have seen, the lines due to the impurity are added to the spectrum of the other metal, and the only effect of an increment of temperature would be to bring out brighter and stronger the lines due to each substance. With a compound it would be very different. Below a given temperature the compound would give out a certain spectrum, but above that temperature the elements would be dissociated, the characteristic lines of each would appear, and the spectrum would be entirely changed. Thus Mr Lockyer arrives at this important conclusion, that with gradually increasing temperature the spectrum of a given substance "will *fade* if it be a compound body, as it will be increasingly dissociated, and it *will not* fade if it be a simple one."

In laboratory practice, when the spectrum of a glowing metallic vapour is required, it is usual to make use of the electric lamp. The electric spark which passes between two poles, one charged with positive and the other with negative electricity, has a very high temperature; and if the poles are made of metal, and the discharge is sufficiently great, small particles of the poles are vaporized, and the

spark is tinged with colour due to the incandescent metallic vapour. In this way the spectra of various metals may be readily examined. If a still higher temperature is needed, then the electric arc is used. In this case carbon points are fixed to the poles, and a small quantity of the substance to be examined is placed on the lower point. Sometimes, however, the electrodes, or poles, are formed of platinum, or some other metal not easily fused, instead of carbon. Taking calcium, iron, lithium, and hydrogen, Mr. Lockyer draws attention to the changes which their spectra undergo at various temperatures, and shows that these changes are precisely such as are to be expected from compound substances.

Take, for example, the chloride of calcium. So long as the temperature is below a certain point the compound has a definite spectrum of its own, at the red end, and no lines due to calcium are visible. As the temperature is raised the spectrum of the salt gradually dies out, and very fine lines, due to the metal, appear in the blue and violet portions of the spectrum. This is such a change as we should expect from a compound. But now let us observe the spectrum of calcium, which we know is an "element." At the temperature of the electric arc the line in the blue is of great intensity, the violet lines, H and K, as they are called, being still thin. In the sun the H and K lines are very thick, and the line in the blue is of less intensity than either, and much thinner than before. The lines H and K are alone visible in the spectrum of α Aquila, the latter being, however, about only half the breadth of the former. Finally, in the spectra of Vega and Sirius—which belong to the hottest class of stars—the H line of calcium is alone visible. A similar series of changes, due to increased temperature, is observed in the spectrum of lithium.

The spectrum of iron is a very complicated one, owing to the number of lines, but there are two sets of three lines each that are very characteristic, and in some photographs these triplets are seen almost alone, but differing in intensity. On comparing photographs of the solar spectrum

and of the spark taken between poles of iron, the relative intensity of these lines is reversed, the lines barely visible in the spark photograph being very prominent in the solar spectrum; while the triplet, which is prominent in the spark photograph, is represented by Fraunhofer lines not half so thick. These facts seem to show that the triplets are due to the vibration of more than one molecule, or molecular grouping; otherwise why should the same increase of temperature cause one set of lines to increase in intensity, and the other to fade?

Mr Lockyer's observations upon hydrogen are highly interesting, and, if we understand him aright, seem to indicate a connexion between that and other metals. By employing a very feeble spark at a very low pressure, the F line of hydrogen in the green portion of the spectrum is obtained without the blue and red lines which are seen when a strong spark is used. Besides these, there is a line *h* in the violet portion which is only seen when a very high temperature is employed. It has been detected as a short line in the chromosphere of the sun, but it was missing in the eclipse of 1878 and in that of 1875, and it is rather remarkable that in both these eclipses the lines of calcium were plainly visible. "When the hydrogen lines were most brilliant in the corona the calcium lines were not detected; next, when, the hydrogen being still brilliant, the *h* line was not present (a condition of things which, in all probability, indicated a reduction of temperature), calcium began to make itself unmistakably visible; and, finally, when the hydrogen lines are absent, H and K become striking objects in the spectrum of the corona." Mr Lockyer also states that he has obtained evidence leading to the conclusion that the substance giving the non-reversed line in the chromosphere, which has been termed *helium*, and not previously identified with any known element, and also the substance giving the line at 1474 of Kirchhoff's scale, termed the coronal line, are really other forms of hydrogen. He has also detected the red and blue lines of hydrogen in the element called indium, but that it was a special form of the substance was evident

from the fact that it registered itself on the photographic plate, although ordinary hydrogen persistently refuses to do so.

It has been suggested that the same molecule may be capable of vibrating in different ways at different temperatures, and thus of yielding different spectra, just as a bell may give out different notes when struck in different ways. Mr Lockyer's reply is that the argument proves too much. "If it demonstrates that the *h* hydrogen line in the sun is produced by the same molecular grouping of hydrogen as that which gives us two green lines only when the weakest possible spark is taken in hydrogen enclosed in a large glass globe, it also proves that calcium is identical with its salts. For we can get the spectrum of any of the salts alone without its common base, calcium, as we can get the green lines of hydrogen without the red one."

Comets and Nebulæ.—We have in a former chapter pointed out the connexion which exists between comets and meteors; it is not improbable that there may also be some connexion between comets and nebulæ. It is quite possible that comets may be fragments of nebulæ thrown off in the early stages of condensation and rotation, before the nebulous mass had assumed a globular form. Sir William Thomson and Professor Tait are disposed to think that true nebulæ are of the same nature as comets, and that instead of consisting of mere masses of gas, they consist really of clouds of stones "banging about" in an atmosphere of hydrogen, and that the heat evolved by the stones colliding is sufficient to render the circumambient air incandescent. Some experiments by Mr Lockyer show that this connexion between nebulæ, meteorites, and comets is highly probable. We give the account in Mr Lockyer's own words:—

"I thought it would be worth while to try what would happen if I enclosed specimens of meteorites, taken at random, in a tube from which I subsequently exhausted the air by a pump. After pumping had gone on for some considerable time, of course we got an approach to a vacuum; and arrangements were made by means of

which an electric spark could pass along this apparent vacuum, and give us the spectra of the gases evolved from the meteorites. Taking those precautions which are generally supposed to give us a spark of low temperature, and passing the current, we got a luminous effect which, on being analyzed by the spectroscope, gave us that same spectrum of hydro-carbon which Mr Huggins, Donati, and others have made us perfectly familiar with as the spectrum of the head of a comet. There, then, we get the atmosphere of meteorites, not necessarily carbonaceous meteorites, but meteorites taken at random, and this atmosphere is exactly what we get in the head of a comet.

"Now let me go one step further; and to take that step with advantage, allow me to refer to another point noticed in the last lecture, which was this—that whereas Schiaparelli had connected meteorites and falling stars with comets, Professors Tait and Thomson, on the other hand, had connected comets with nebulæ, both of them being, according to these physicists, clouds of stones. Now, how was one to carry these spectroscopic observations into the region of the nebulæ? A Leyden jar was included in the circuit, and we had what is generally supposed to be an electric current giving us a very much higher temperature than we had before. What, then, was the spectrum? The spectrum, so far as the known lines were concerned, was the spectrum which we get from the nebulæ; for the hydro-carbon spectrum, which we get from the atmospheric meteorites at a low temperature, was replaced by the spectrum of hydrogen; the spectrum of hydrogen coming, of course, from the decomposition of the hydro-carbon, with the curious but at present unexplained fact that we got the spectrum indications of hydrogen without indications of carbon. In my laboratory work I have come across other curious cases in which compound vapours, when dissociated, only gave us one spectrum at a time—by which I mean that in a vapour consisting of two well-known substances, under one condition we only get the spectrum of one substance, and under another

condition we get the spectrum of the other substance alone, so in others again of both combined. The evidence seems, therefore,—though I do not profess to speak with certainty, —entirely in favour of the ideas of Sir William Thomson and Professor Tait on the one hand, and of Schiaparelli on the other."*

Just as the earth is one planet among many others, some larger, some less, some nearer the sun, others more remote, so the sun itself is a star among thousands of others, some larger, some probably less, some hotter, some cooler. The spectroscope reveals to us the fact that the constitution of the stars is similar to that of the sun; that they all consist of solid, liquid, or densely gaseous nuclei, surrounded by glowing vapours which intercept a portion of their light. Probably in the four different classes of stars to which we have alluded we have four stages in the history of the sun: they indicate a gradual cooling down. The sun has passed into the second stage, and some day it will probably pass into the third and fourth; but we can scarcely calculate the immense lapse of time it would require to bring those changes about.

The Sun.—But just as the different classes of stars throw some light upon the history of the sun, so the present condition of the sun helps us to understand the physical constitution of the stars. We have stated in a former chapter that the bright surface of the sun is called the photosphere, and that in this photosphere are the sun-spots. Sir William Herschel held the opinion that the sun itself might be a cool habitable globe, and that the photosphere was an atmosphere of cloud which here and there was broken open, allowing the cool dark body of the sun to be seen. Spectrum analysis shows that this is not the case; for it proves that the darker parts of the sun-spots are only dark by comparison with the brighter surface, and that they yield a spectrum similar, only fainter. This, however, is probably due to the absorption of a greater thickness of atmosphere, as the spots are hollows in the bright surface.

* *Why the Earth's Chemistry is as it is.*

Immediately outside the photosphere is the reversing layer, and rising high above it is the chromosphere. This, as we have before stated, is the region of the red flames or prominences which were first observed during a solar eclipse. So many improvements, however, have been introduced into the spectroscope, and so expert have physicists become in its use, that these red flames can now be seen whenever the sun is visible, and can be studied at leisure, though of course they are seen more distinctly during an eclipse. From the labours of Young, Lockyer, and others, we learn that the red prominences are of two kinds, eruptive and cloudy. The former consist of glowing vapours which rush upward with enormous velocity from the sun's surface, and, after reaching a height varying from 20,000 to more than 100,000 miles, spread out laterally, subsiding gradually to the surface, but often continuing to float for days at an enormous height. These are generally seen in the neighbourhood of the sun-spots. Cloudy prominences, as their name implies, are clouds of glowing vapour, often seen at a great height, rarely, however, above 80,000 miles, and are generally over the sun's equatorial and polar regions, not over the spot-zones. They are not so bright as the eruptive prominences, and consist chiefly of hydrogen, while the latter show traces of sodium, magnesium, iron, and other metals. Prominences of both kinds are few in number and small in dimensions when the sun shows few spots. The almost total absence of red flames during the solar eclipse which was visible in July 1878 was the subject of general remark among the observers.

Another characteristic feature of the last solar eclipse was that the corona was less brilliant than usual. In former eclipses it had been noticed that while a portion of the coronal light gave a faint continuous spectrum, another portion gave a spectrum of bright lines, and in 1871 these lines were very bright, showing the presence of large quantities of gas. The observations of 1878 show a continuous spectrum without any bright lines. The explanation suggested is that "the gases which were high

up in the sun's atmosphere at the last epoch of maximum sun-spots (1871) have almost entirely retreated to a lower level; as these gases are to a large extent carriers of heat from the interior to the exterior of the sun, the exterior is cooled in their absence, and indeed cool enough to allow it to hold in suspension a larger percentage of solid and liquid particles to which the continuous spectrum is due. A natural suggestion touching these particles is that they consist of meteoric matter, and all the phenomena to which attention has been drawn can be explained by supposing that these meteorites surround the sun, and at the minimum sun-spot period they can exist lower down in consequence of the reduced temperature of the sun's atmosphere at the time."—*Nature*, August 22, 1878.

It will be seen that the spectrum of the corona is mixed and variable, sometimes consisting of a faint continuous spectrum crossed by bright lines, while at another time the bright lines are almost entirely absent. There is evidence to show, also, that a portion of the coronal light is reflected sunlight. This had been suspected for some time, but observations made during the last eclipse placed the question beyond a doubt. It will be seen, also, that the connexion which we traced between sun-spots and solar-prominences has been extended to the corona. Sun-spots may either be caused by up-rushes of gas from the interior of the sun into its higher atmosphere, or, as Mr Lockyer thinks, down-rushes, caused by return convection currents. In either case we see that the maximum sun-spot period is one of great solar energy, and we know that it coincides with a period of magnetic storms, brilliant auroræ, heavy rainfall, and other terrestrial phenomena. One other remark before we leave this subject. Though the corona was in 1878 less brilliant than usual, yet more than one observer noticed that it extended for an unusual distance from the sun, especially in the neighbourhood of the solar equator. Professor Newcomb and others, however, believe that these wing-like appendages were not extensions of the corona, but belonged to the zodiacal

light which surrounds the sun, and which by some astronomers is supposed to extend in an attenuated form beyond the limit of the earth's orbit. The spectrum of this light has been obtained more than once, and as it is continuous, though very faint, it is supposed to result from the same kind of meteoric matter which is believed to exist in the corona. We have already mentioned the position which the zodiacal light occupies in the nebular hypothesis. Assuming that such rare and volatile fragments of matter as the zodiacal light is supposed to be composed of ever exist beyond the limits of the earth's orbit, they would offer little appreciable resistance to the motion of the planets, not only on account of their extreme rarity, but because their motion would be the same as that of the planets themselves.

CHAPTER XII.

Organic Life.

Let us now turn once more to the nebular hypothesis: according to this theory, the cloudy nebulous matter, acted upon by gravity, condenses towards the centre, and in condensing partakes of a vorticose or whirling motion. The nucleus of the nebula increases in density and temperature, and eventually forms a sun; but in the process of condensation it throws off rings, owing to centrifugal force, which in time break up and form planets, while the planets in turn throw off satellites. In the meteoric matter which exists in the coronal atmosphere of the sun, and to a still larger extent in the zodiacal light, we have very probably some remains of the nebulous matter out of which the sun was originally condensed. And it is not impossible that in the meteor swarms we have fragments of matter thrown off by the nebulæ during the process of their condensation—chips, as it were, in the great workshop of the Divine Architect. These fragments, in the meantime, serve some important purpose in the economy of the solar system, with which we are not yet acquainted, but are probably destined at some future time to form new worlds. Just as the aqueous vapour which exists in our atmosphere is gradually condensed by cold into a visible mist, and this by cohesion of the minute particles is formed into rain-drops, so the comparatively small fragments of meteoric matter may combine to make asteroids, and these coming into collision may eventually form planets.

Of course, if the nebular hypothesis be correct, our earth, as well as the other members of the solar system, must at one time have possessed a very high tempera-

ture — so high, in fact, that probably nothing could have existed either in a solid or liquid form. But from that remote period when it first began an independent existence a process of cooling has gone on, and this secular cooling is still at work. We have in former chapters traced the various stages through which the earth passed before it became suitable as the abode of man. We have noticed the formation of dry land, the process of denudation, and the gradual progression in animal and vegetable life. A few additional remarks on the origin and distribution of organic life may fitly conclude this brief outline of the history of the earth.

Origin of Plants.—The French naturalist Buffon, assuming the truth of the nebular hypothesis and the fact that the earth once existed in a highly incandescent state, argues that as the cooling of the earth has been a gradual process, the Polar regions must have been the first in which the heat was sufficiently moderate for life to have appeared upon it. Count Saporta worked out this idea in detail in a paper read in 1875 before the International Congress of Geographical Science which met at Paris. He points out that the older and richer fossiliferous beds are met with in latitudes 50° to 60°, and beyond them. The Laurentian rocks reach their highest development in Canada; the most characteristic Silurian strata are found in the United States, England, Bohemia, and Scandinavia. Beds of coal have been found almost as far as the northern limit of land, but they become exceptional to the southward of 35°. Hence Count Saporta argues that during the Carboniferous era the climatic conditions favourable to the formation of coal were not everywhere prevalent on the globe; for that, while the southern limit of this formation may be approximately drawn, its northern limit must have extended almost to the Pole itself.

Count Saporta also points out that all formations subsequent to the Carboniferous, including the Oolitic, Cretaceous, and Tertiary, are alike abundantly represented in the Polar area, and that their fossils closely resemble those of lower latitudes. The first indication of a cooler climate

in these high latitudes is afforded by coniferæ which appear in the Polar lower cretaceous formations. These are followed by the first appearance of deciduous trees, which marks a period when the summer and winter seasons first became strongly contrasted. Before this time the native heat of the earth probably masked the heat of the sun. During the Miocene period there was a profusion of plants in the Polar area, the representatives of which are now to be sought for 40° farther south. They were probably driven south by the gradual advance of the cold Glacial period.

Mr Thistleton-Dyer, in a paper read before the Geographical Society in August 1878, comes to almost the same conclusion as Count Saporta, though starting from a totally different point. He first gives a brief outline of the principal existing floras of the present day, their relation to each other, and to the fossils of the different geological epochs, and arrives at the conclusion "that the northern hemisphere has always played the most important part in the evolution and distribution of new vegetable types, or, in other words, that a greater number of plants have migrated from north to south than in the reversed direction, and that all the great assemblages of plants which we call floras seem to admit of being traced back at some period in their history to the northern hemisphere." *

A good deal of what sometimes looks like an arbitrary distribution of plants may be explained by migration. If we are correct in looking upon the Polar area as the cradle of vegetation, then gradually as the climate grew cooler the less hardy plants would migrate southward; while a change in the opposite direction, such as succeeded the Glacial period, would cause a migration to the north. Stragglers in both cases would be left behind. If the movement were southward, these stragglers will be found in sheltered valleys; if northward, on the tops of mountains. Plants identical with others found on the shores of the Mediterranean are met with on Kilimandjaro and on the Peak of Cameroons. The tops of the loftiest British

* *Proc. R. G. Society*, vol. xxii. p. 441.

mountains have a flora similar to that of the mountains of Scandinavia. The rare *Eriocaulon* is found in the Hebrides, in Connemara, and in North America, and nowhere else. During the Oolitic period the cycad and *Araucaria* flourished in England; the latter has never since been found north of the Equator. The *Cycadeæ* are now met with in South America, in Africa, and in Australia, but the genera are different in the three continents. The Jurassic rocks of India have yielded fossil forms nearly identical with those found in the Lower Oolites of Yorkshire and in the limestones of Stonesfield (Oxfordshire) and Solenhofen.

Animals.—In a former chapter we mentioned the various regions into which Mr Wallace has divided the globe with reference to the distribution of animals. It will also be recollected that he too looked upon the northern hemisphere as the cradle of animals, just as Mr Thistleton-Dyer looks upon it as the cradle of the plants; and that both consider that organic life has thence proceeded in successive waves of migration to different parts of the world.

It would appear that during the middle of the Tertiary period a continuous sea or strait extended from the Bay of Bengal to the Atlantic Ocean, thus cutting off what have been termed the Ethiopian and Oriental regions from the great northern continent. At the same time, and down to a comparatively recent period, the north of Africa was united to Europe both at the Strait of Gibraltar and in Italy, while Asia Minor was united to Greece. Thus there was free communication to all parts of the Palæarctic region. We have evidence to show, also, that about the same time —that is, during the Miocene age—Central Europe as well as Central Asia enjoyed a warm and genial climate, and that among the animals which then inhabited this region were elephants, rhinoceroses, tapirs, horses, giraffes, antelopes, hyænas, lions, and numerous apes and monkeys. The fossil remains of several of these animals have been found in England and France. Antelopes were abundant in Greece, and two species of giraffes inhabited Greece and the district now occupied by the Sivalik hills in India. As the climate of Europe and Asia gradually grew colder, the

majority of these animals moved southward, and, crossing the Mediterranean by the natural bridges which then existed, entered Asia Minor and the north of Africa. It is supposed that the "continuous sea" to which we have already referred became dry land by an elevation of its bed about the middle of the Miocene period, and it is to this period that we assign the migration into tropical Africa of the large animals which now characterize that region. A number of the smaller and more defenceless of the ancient inhabitants would soon become exterminated, and perhaps in the scaly ant-eater of the Cape and the lemurs of Madagascar we have remnants of this ancient fauna. It is probable that bears and deer are wanting in Africa because they are comparatively late developments, and were either unknown or rare in Europe until later Miocene or even Pliocene ages, and by this time the connexion between Europe and Africa had become interrupted as it now is.*

We have dwelt thus fully upon one particular migration because it is typical of the others, and because, also, being the most recent, it can be the more easily traced. The preponderance of marsupial forms in Australia, and their almost entire absence from the rest of the world, may be explained by supposing that the Australian continent was connected with Asia in early geological times, but that all communication between the two has been severed since the Oolitic period. Professor Owen has pointed out the remarkable similarity there is between the existing flora and fauna of the Australian continent and the organic remains of the British Oolite. Araucariæ and cycadeous plants, which are characteristic of the Oolitic system, likewise flourish on the Australian continent, "where marsupial quadrupeds abound, and thus appear to complete a picture of an ancient condition of the earth's surface which has been superseded in our hemisphere by other strata and a higher type of mammalian organization."

In a similar manner we may account for a preponderance of genera belonging to the edentata now found in

* *Proc. R. G. Society*, vol. xxi. p. 505.

South America. The ancestors of those animals no doubt migrated from the Palæarctic region at an early period, and entered America either by way of Greenland or by Behring Strait. They then advanced southward, but successive waves of more highly organized types have destroyed all trace of them in the Nearctic region. In South America, however, they have been in a great measure protected. The channel of communication between the northern and southern divisions of the new world is very narrow, and there is geological proof that at more than one period the communication has been entirely interrupted.

It may be objected that animals which now inhabit the tropics could not endure the cold they would suffer in a journey either through Greenland or Alaska. The reply is that there is abundant evidence to prove that in Miocene times—whatever the cause may have been—Greenland enjoyed a genial climate, and possessed a luxuriant vegetation, including magnolias and other large-leaved evergreens; there is no difficulty, therefore, so far as climate is concerned, in supposing that the original home of all the native animals of both North and South America was the Palæarctic region.

Summary.—We thus conclude our brief sketch of the natural history of the earth and of its relations to the other parts of the universe. We have seen that the vegetation which now clothes our globe, and the animals which now inhabit it, are the descendants of races of plants and animals which flourished during geological periods; that the present distribution of organic life is owing to successive waves of migration proceeding from a common source, and that this common source was the northern portions of Europe, Asia, and North America. Geology also teaches us that in the earliest period of the world's history the types of animal and vegetable life were of the lowest order, that there has been a gradual progression from lower to higher forms in successive periods, and that this gradual progression has been accompanied by a gradual change in the external conditions of the globe. The uniformity of animal and vegetable life noticed among primary and secondary rocks,

and the high temperature which marks the Oolitic and Carboniferous periods, favour the theory that in the earlier stages of its history the earth had a much higher native temperature than at present, and that a process of secular cooling has been going on, and is not yet complete. As the earth gradually cooled down it would diminish in bulk, and the rigid crust, trying to accommodate itself to the lessening nucleus within, would be crumpled again and again. This crumpling would have the effect of raising the mountain chains, and also of causing that oscillation in the general surface of dry land which may still be traced in areas of depression and elevation. But this change in the earth's crust would have another effect: the downward tendency of certain parts would produce friction, this friction would result in the evolution of heat, and thus we explain the origin of that igneous force which causes earthquakes and volcanoes.

As the earth is a planet, we may, by studying the present physical constitution of the other planets, obtain some knowledge of the past history of the earth. It is very probable that at one period of the earth's history it was a merely incandescent gas, and it is very possible that the larger planets, Jupiter, Saturn, Uranus, and Neptune, are still in a gaseous condition. The specific gravity of Jupiter is only equal to that of water; Saturn and Uranus are even less dense. It is probable that these bodies still retain a large portion of their original temperature, and this idea is strengthened by the fact, which the spectroscope reveals to us, that Uranus gives out a certain amount of native light. The rings of Saturn are interesting as showing to us the probable mode in which satellites have been formed from their primaries. The rapid rate of rotation causes first a flattening at the poles and a protuberance at the equator. This protuberance at length breaks off and forms a ring, and this ring, afterwards breaking up, is formed into satellites. The fact that the larger planets have more satellites than the smaller ones may be owing to two causes:—(1.) First, their rate of rotation is much greater; (2.) The composition of the larger

planets being of so much less density, the protuberance at the equator would break away much more easily than in bodies of the same density as the earth.

But just as the various moons have been thrown off from the planets, so the planets themselves are probably but fragments of the sun, and thus there is a similarity in the physical constitution of the whole solar system. It does not follow because the exterior planets are still either in a liquid or gaseous state, that therefore they have been formed at a later period than the earth. The moon, in all probability, is a fragment of the earth, and must therefore have been formed subsequently to it; yet it is now a dead planet. It has parted with all its native heat, and lost its air and moisture. It has cooled more quickly than the earth owing to its smaller size, and in the same way the earth and the other inferior planets may have cooled more rapidly than Jupiter and Saturn owing to their less bulk, and thus they have at present much greater density.

That the climatic conditions of the earth are intimately connected with the sun, no one will be disposed to deny. Upon it we depend for our heat and light, the regular recurrence of day and night, the change in the seasons, and the atmospheric and oceanic currents. But recent researches seem to show that the irregularity in our seasons may also be connected with changes on the solar surface, and that not only magnetic disturbances, but periods of famine, commercial crises, and even prevailing epidemics, are more or less closely connected with the periodicity of the sun-spots. What are the causes which occasion those great disturbances which result in the solar spots we do not at present know, but there seems little doubt that they are connected in some way with the movements of the larger planets.

But in seeking to trace out the history of the earth we do not even stop with the sun, and the same hypothesis which supposes the planets to have been formed from the sun, points out also that the sun has probably been condensed from nebulous matter such as we still see in

different parts of the universe. We find different forms of nebulæ illustrating different stages in the process of condensation. In one stage there is simply a cloud-like mass; in another it has assumed a spiral form, showing that there is a rotation among the various particles of which it is composed; in another we have a globular form surrounded by a ring ready to break up and form other stars or planets. Then, again, just as the planets illustrate different stages in the earth's history, so the fixed stars illustrate different stages in the history of the sun. We have here, again, a slow secular cooling. Some stars are hotter than the sun, others much cooler. It is very probable, therefore, that the sun had at one time a much higher temperature than it has now; it is also probable that at some future time it will be much cooler. This gradual loss in the amount of heat and light radiated by the sun must affect the climate of the earth and that of the other members of the solar system.

There is one other point to notice before we conclude —the sun's proper motion in space. We have seen that the sun is travelling with considerable velocity in a given direction among the stars. Now, all analogy leads us to believe that the direction in which the sun is moving must be a portion of a curve, and that the centre of our system is moving round some other centre. What that centre is, and whether it is itself at rest, we do not at present know. But when we recollect in how very many instances proper motion has been detected among the stars, we are led to believe that probably the whole of them are connected together in some way by the laws of gravitation. Thus we find that the earth is intimately connected not only with the other parts of the solar system, but probably also with the most distant stars; and we are thus able in some measure to realize the force of Carlyle's words,—"Not a leaf rotting on the highway but is indissoluble portion of solar and stellar systems."

PHYSIOGRAPHY.

First Stage, or Elementary Course.

The candidate will be expected to have a knowledge of ordinary descriptive and physical geography so far as required by the 5th and 6th standards of "the new Code" and of the specific special subjects of secular instruction—principles of mechanics and physical geography. Questions may be set in these subjects.

The parts played by gravitation, cohesion, and chemical affinity in producing chemical and physical differences in matter.

Elementary ideas of the various conditions of matter as regards energy, embracing heated states and electric and magnetic states.

Elementary notions of chemical action, the formation of binary compounds.

Breaking up of compound matter into simpler forms. The chemical elements.

Water, its composition and different states.

Chemical and physical character of the crust of the earth. Rocks, stratified and unstratified. Inorganic materials :—the more frequent simple minerals and rocks formed of them :—granite, volcanic products, ancient and modern ; sedimentary rocks, conglomerate, sandstone, shale ; limestone, gneiss, slate, marble, sand, mud, surface soil. Materials partly produced by organisms :—Coal, peat, chalk, coral, limestone. Bodies of which these are compounds.

The chemical elements of which the crust is chiefly composed.

Observations indicating an increased temperature in the interior of the earth.

Volcanic phenomena and distribution of volcanoes.

Earthquakes and slow upheavals and subsidences of the earth's crust.

The Sea :—

Salts dissolved in sea water, depth and form of sea bottom, remarkable inequalities.

The chief currents.

Distribution of temperature and density.

Phenomena of arctic and antarctic regions. Floes, pack ice, icebergs, etc.

Action of the sea upon the Earth's crust.

Influence of the sea in the distribution of climate.

The Atmosphere :—

Height and composition; atmospheric pressure; use of the barometer.

Distribution of temperature, horizontal and vertical.

Use of the thermometer.

Evaporation and condensation.

Aqueous vapour, rainfall, ice, and snow.

Regions of extreme dryness and of great rainfalls.

The prevailing air currents; cyclones.

General conditions of climate.

Action of rain, springs, rivers, and glaciers upon the earth's crust.

General ideas of the changes which the earth's surface has undergone in the past, and of the evidence as to the succession of various forms of life.

Elementary notions as to the effects of terrestrial electricity and magnetism. Thunderstorms; aurora; the mariner's compass.

Second Stage, or Advanced Course.

Questions may be set in all the topics included in the Elementary course, and, in addition, in the following ones:—

Principles of construction of the telescope.

The solar system :—

Plane of the ecliptic :—Precession of the equinoxes; inclination of the equatorial planes of the chief planets to the ecliptic; elliptic orbits; changes in the line of apsides; nodes.

The real motions of the earth and apparent motions of the stars; measurement of time and longitude.

Measurement of the surface, size and true shape of the earth. General idea of the work of geodetical surveys and instruments employed. Map projections.

Measurement of the earth's density. Methods employed and results obtained. The nature of the earth's interior.

Measurement of the distance of the moon, and of the sun; dimensions of the solar system, and of the distances of the stars.

Theory of ether. Action of matter on ether. Propagation and velocity of light.

The principles of spectrum analysis.

General physical and chemical description of extra terrestrial matter:—

Classification into hot and cold masses; bodies studied by their radiation alone; by their radiation and absorption; by their reflection; general idea of distribution of these masses.

(1.) Nebulæ and comets; meteors and meteorites.

(2.) Stars:—Classification according to their spectra; variable stars; coloured stars.

(3.) The planets:—Atmospheres; cloud belts; temperatures; crust of Mars; densities.

(4.) Satellites; the moon; density of the satellites of the other planets.

Physical and chemical constitution of the sun.

Corona; chromosphere; reversing layer; photosphere; spots; faculæ.

Distribution of sun spots and prominences; spot and prominence periods.

The earth compared with the other members of the solar system.

The secular cooling of the earth.

The present conditions of non-terrestrial matter as throwing light on the past history of the earth. Kant's hypothesis. Evidence as to the condensation of nebulæ into stars. Saturn as a type of the formation of rings during condensation.

The effects of solar radiation:—

Effects on the vegetable kingdom; on the atmosphere; changes in barometric pressure; how air currents are produced; changes of direction in currents; effects on the ocean.

Explanation of the daily and yearly changes in the meteorology of the earth. Possible 11 yearly changes.

The various causes of secular changes of climate and their effects.

Combined effect of the sun and moon on the ocean :—The tides.

Distribution of terrestrial magnetism and electricity; description of instruments by which it has been determined; the various periodic changes in the magnetism of the earth.

HONOURS.

The candidate must possess a sound knowledge of all the subjects contained in the syllabus, but he will be expected in addition to show a thorough acquaintance with one of the main groups, including the advances which have recently been made in it.

1877.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *eight* questions.

The *first four* questions must be *attempted* by you, and you are then at liberty to select four others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers in brackets.

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51. What are deltas? How are deltas formed? Name six of the largest deltas in the world. (15.)

52. Why does rain fall in such great abundance in the west of Ireland? What is meant by the statement that the mean annual rainfall of a place is 70 inches? What becomes of the water which falls upon the earth in the form of rain? (15.)

53. What is meant by the snow-line? Why is the snow-line sometimes higher on one side of a mountain chain than on the other? Why do glaciers descend below the snow-line? (15.)

54. What is a volcano? Name the *active* volcanoes of Europe, and state in what parts of the same continent *extinct* volcanoes occur. (15.)

55. State, in the order of their relative abundance, the eight chemical elements which enter most largely into the composition of rocks. (10.)

56. What is the difference in composition between peat and coal? By what changes would the former pass into the latter? (10.)

57. Of what materials are clay, shale, and slate chiefly composed, and in what respect do these rocks differ from one another? (10.)

58. What is the principal work performed by rivers in modifying the features of the earth's surface? Explain the mode of origin of the winding curves in which rivers so frequently flow. (10.)

59. Draw a sketch map of the Atlantic Ocean, and indicate upon it the courses of the chief of the great currents. (10.)

60. What are the differences between continental and insular climates, and how are these differences caused? (10.)

61. In what direction does a magnetic needle in this country point, and why does it not everywhere assume a due north and south direction? (10.)

62. Why are coral reefs limited to certain restricted areas of the earth's surface? (10.)

Second Stage, or Advanced Examination.

Instructions.

You are permitted to *attempt* only *six* of the following questions, and *the three which stand first upon the paper* must be included among these.

The value attached to each question is indicated by the numbers in brackets.

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71. A steamer crosses the Pacific from Vancouver's Island to Otago. State the nature and direction of the great permanent air-currents which she may be expected to encounter at different points during the voyage, and explain the causes to which each is due. (18.)

72. Explain the precession of the equinoxes. (19.)

73. How has the chemical composition of the solar atmosphere been determined, and how can we measure the velocity with which the various vapours move in that atmosphere? (18.)

74. State the various grounds on which it is inferred that a high temperature exists in the earth's interior. (15.)

75. Explain the origin of ground-ice, pack-ice, and icebergs. (15.)

76. Describe the several methods by which beds of limestone are now being formed upon the earth's surface. (15.)

77. What conclusions concerning the origin of the physical features of the moon have been deduced from its telescopic appearance? (15.)

78. How has the size of the earth been determined? (15.)

79. What are the three elements to be observed before the state of the earth's magnetism at any place and time is determined? (15.)

Honours Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *four* questions, but these may be selected from any part of the paper.

The value attached to each question is the same.

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91. State the various methods by which the density of the earth has been determined. What are the results which have been arrived at? Compare the density of the earth with that of the other planets.

92. What are the different theories which have been put forward in explanation of the origin of volcanic cones and craters? State the arguments for and against each of these theories.

93. Explain the nature and probable mode of origin of the several different kinds of deposits now being formed in the deepest explored portions of the ocean.

94. State the chief differences which have been observed in the stellar spectra, and the conclusions which may be drawn from these differences.

95. Describe the instruments in a self-recording magnetic observatory.

96. Give an account of the results which have been obtained by recent researches in connexion with *one* of the following subjects:—

(*a.*) The constitution of the sun.

(*b.*) The origin of ocean currents.

(*c.*) The distribution of temperature on the earth's surface during former periods of its history.

(*d.*) The nature of the liquids occupying minute cavities in the crystals of rocks.

1878.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *eight* questions.

The *first four* questions must be *attempted* by you, and you are then at liberty to select four others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers in brackets.

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51. The River Rhone enters the Lake of Geneva as a muddy stream, and leaves it as a perfectly clear one. State the source whence the sediment carried by the river is derived, and what becomes of it. Explain the changes which are being produced in the physical features of the country by the removal and re-deposition of the material carried by the river. (15.)

52. What is a "bore"? How are bores produced? Name three rivers which exhibit this phenomenon. (15.)

53. How is dew formed? State the conditions of atmosphere which interfere with the formation of dew; and explain how the deposition of dew is checked by these conditions. (15.)

54. In what respects do a volcano and a geyser resemble one another, and in what respects do they differ? Name the principal districts on the globe in which geysers are found. (15.)

55. Name four of the most common minerals which enter into the composition of the earth's crust, and state the elements of which each is composed. (10.)

56. Describe the minute structure of a piece of chalk, and show how, by simple experiments, the two oxides of which it is composed may be respectively isolated. (10.)

57. State the different methods by which the heights of mountains can be determined. (10.)

58. Draw a sketch-map of Africa, and indicate upon it the positions of its great lakes and the courses of its principal rivers. (10.)

59. What are isobars? State the causes to which their continual changes in position are due. (10.)

60. Describe the mode of origin of icebergs. (10.)

61. What are the magnetic poles, and what do you know about their geographical position? (10.)

62. In what parts of the globe are elephants now found?

Is there any evidence that they once lived in other areas? and if so, state the nature of that evidence. (10.)

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *six* of the following questions, and *the three which stand first upon the paper* must be included among these.

The value attached to each question is indicated by the numbers in brackets.

---

71. Describe the principal methods which have been devised for determining the longitude of a place. (18.)

72. State the general facts at present known concerning the temperature of the water of the ocean. (19.)

73. What are the nature and composition of the chief materials ejected from volcanic vents? (18.)

74. Explain the principle on which the sending of storm warnings from America is based, and state the causes which may prevent these predictions from being fulfilled. (15.)

75. How has it been proved that the earth is not a perfect sphere? (15.)

76. State what you know about nutation. (15.)

77. What is an "arc of parallel," and an "arc of meridian?" Give examples of both. (15.)

78. What are earth currents? (15.)

79. Compare the chemical composition of the crust of the earth with that of the sun's atmosphere, comets, and nebulæ. (15.)

Honours Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *four* questions, but these may be selected from any part of the paper.

The value attached to each question is the same.

---

91. Give an account of the apparatus by means of which observations have been made in the deeper parts of the ocean, and describe the general form of the bed of the Atlantic Ocean.

92. Explain the methods by which the depth of the shock producing an earthquake-wave can be determined.

93. State the chief arguments that have been adduced against the hypothesis that the earth consists of a solid shell with a liquid interior.

94. Describe the phenomena presented by auroræ, and state what you know concerning the hypotheses which have been put forward to account for their production.

95. State the facts which have led to the view that meteorological changes, and changes in terrestrial magnetism, are connected with one another.

96. Give an account of the results which have been obtained by recent researches in connexion with one of the following subjects:—

(*a.*) The density of the earth.

(*b.*) Double and multiple spectra of the same elementary body.

(*c.*) The measurement of the sun's distance.

(*d.*) The cause of the movement of bubbles in the liquids enclosed in minute cavities of the crystals of rocks.

(*e.*) The existence of man during or before the Glacial epoch.

1879.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *eight* questions.

The *first three* questions must be *attempted* by you, and you are then at liberty to select five others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers in brackets.

---

1. What is the number of known chemical elements? Name the six elements which occur in greatest abundance in the crust of the earth. State the condition in which the metallic elements generally exist in that crust. (15.)

2. When water is left standing in a vessel out of doors, it gradually disappears. State what becomes of the water, and under what conditions of atmosphere it will disappear most rapidly. (15.)

3. State what rock-constituents are carried by rivers to the sea in suspension and solution respectively; and describe what becomes of those materials when they reach the sea. (15.)

4. How do you explain the fact that fringing coral reefs

generally occur in volcanic areas, and atolls, encircling-reefs, and barrier-reefs in non-volcanic areas? (11.)

5. Describe the principle of the construction of the mercurial barometer. (11.)

6. What are moraines? Name the different kinds, and describe the manner in which they are formed. (11.)

7. Draw a sketch-map of the Mediterranean Sea, showing the positions of the chief islands. (11.)

8. Name the minerals which occur in a piece of granite, and describe their chemical composition. (11.)

9. What is the chemical composition of a piece of common coal, and how does it differ in composition from peat on the one hand and anthracite on the other? (11.)

10. What is the cause of the noise heard during thunderstorms? (11.)

11. Describe some of the forms found in snowflakes, and explain their origin. (11.)

12. What evidence have we that lions and tigers once lived in this country? (11.)

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *six* of the following questions, and *the three which stand first upon the paper* must be included among these.

The value attached to each question is indicated by the numbers in brackets.

---

21. Draw the earth, as seen from the sun at the two solstices and equinoxes, showing the direction of its axis and the positions of the north and south poles. (18.)

22. Describe the trade-winds, and state the causes to which they are due. (18.)

23. State the different kinds of evidence from which it is inferred that certain parts of the earth are being upheaved, and others are subsiding. (19.)

24. Explain the cause of the difference between the climates of London and Moscow. (15.)

25. Name the several gases of which the atmosphere is composed, the proportions in which they are present, and the manner in which they are united with one another. (15.)

26. What proofs have we of the existence of a high temperature within the earth? (15.)

27. Describe a transit circle and its uses. (15.)

28. How does a dipping-needle behave at the magnetic poles, and why? (15.)

29. What terrestrial phenomena seem to be connected with the number of spots seen on the sun at different times? (15.)

Honours Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *four* questions, but these may be selected from any part of the paper.

The value attached to each question is the same.

---

41. Explain the construction of any forms of seismometers or seismographs with which you are acquainted.

42. Mention the several theories which have been advanced to account for the existence of the great rock-basins occupied by lakes; and state the arguments for and against each of these theories.

43. Describe the composition of the different classes of meteorites, and compare it with that of the earth's crust.

44. State what you know about the spectrum of Sirius and Uranus respectively; and the conclusions which have been drawn from the observations.

45. How has the connexion between luminous meteors and comets been established, and what is the nature of the connexion?

46. Give an account of the results which have been obtained by recent researches in connexion with one of the following subjects:

(*a.*) The distance of the sun as determined by observations of Mars at apposition.

(*b.*) The spectrum of oxygen.

(*c.*) The nature of volcanic products during the older Palæozoic periods.

(*d.*) The existence of great continental "ice-sheets."

1880.

First Stage, or Elementary Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *eight* questions.

The *first three* questions must be *attempted* by you, and you are then at liberty to select five others from among the remaining questions on the paper.

The value attached to each question is indicated by the numbers at the end of the question.

---

1. Name the binary compounds which are united to form a piece of limestone. State how these may be separated from one another, and describe the characters presented by each of them. What elements are present in these binary compounds, and what is the general character of each of these elements? (15.)

2. Describe the construction and use of a thermometer, and explain the method by which thermometers are graduated. (15.)

3. Explain, by the aid of a diagram, the mode of origin of springs. How does the water of springs differ from rain-water? (15.)

4. Why is the south-west wind in this country usually accompanied by rain, while the east wind brings dry weather? (11.)

5. Explain what is meant by the "dew-point." (11.)

6. What are fiords, and how do you suppose them to have been formed? (11.)

7. Describe the phenomena called *rouches moutonnées*, and explain how they are formed. (11.)

8. Draw a sketch-map of Hindostan, showing the position of its great mountain ranges and rivers. (N.B.—Names must be given.) (11.)

9. Name six of the minerals which occur most commonly in igneous rocks, and describe their composition. (11.)

10. How is kaolin derived from granite? Describe the several stages of the process. (11.)

11. What is the cause of the interval which elapses between a flash of lightning and its accompanying thunderclap? If this interval, in any particular case, were found to be 11 seconds, what inference would you draw from the fact? (11.)

12. What is meant by the statement that certain forms of life have become extinct? State some of the causes which have brought about the extinction of animals, and name any animals which have become extinct since the appearance of man upon the earth. (11.)

Second Stage, or Advanced Examination.

INSTRUCTIONS.

You are permitted to *attempt* only *five* of the following questions, and *the two which stand first upon the paper* must be included among these.

The value attached to each question is indicated by the numbers at the end of the question.

---

21. State what you know about the apparent movements of the stars, and the causes which give rise to them. (23.)

22. Explain the methods by which the quantity of material carried down by rivers, in suspension and solution respectively, can be determined. How may this be made to gauge the rate of subaerial denudation within the river basin? (23.)

23. Describe the monsoons, stating the periods at which they blow, the countries in which they are felt, and the causes to which they are due. (18.)

24. Explain the action of plants and animals upon the constituents of the atmosphere. (18.)

25. Describe the principle of the construction of the aneroid barometer. (18.)

26. What are the views entertained at present concerning the nature of Saturn's rings, and what are the facts on which these views are based? (18.)

27. Explain the terms "dispersion" and "minimum deviation," as applied to a ray of light. (18.)

28. How is the intensity of terrestrial magnetism at any place of observation determined? (18.)

Honours Examination.

INSTRUCTIONS.

You are permitted to *attempt* all, or any, of the questions. The value attached to each question is the same.

---

41. Explain the several theories which have been proposed to account for the spasmodic action of geysers, and state the arguments for and against each of these theories.

42. Explain, by the aid of a sketch-map, the course of the tidal wave around the British Islands.

43. State what you know about the spectrum of α Lyræ and the sun respectively, and the conclusions which have been drawn from the observations.

44. State the probable climatic conditions of Mars and Jupiter.

45. Give an account of the results which have been obtained by recent researches in connexion with one of the following subjects:—

(*a.*) The nature of the sun's corona.

(*b.*) The microscopic character of the sedimentary rocks.

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